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Journal
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Devoted to Science and the Mechanic Arts

Vol. 207 FEBRUARY, 1929 No. 2

# SOME LONG DISTANCE TRANSMISSION PROBLEMS.*

BY

H. MOURADIAN.

Toll Fundamental Plan Engineer,
The Bell Telephone Company of Pennsylvania.

I HAVE chosen for the subject of my paper "Some Long Distance Transmission Problems." The last four or five years have been of stirring interest to all students of transmission. There has been a great deal of progress during this period in both the transmission of power and that of speech. The power engineers are developing a more complete understanding of the practical possibilities of the art of transmitting power to a distance. Judging from the experimental trials of interconnected lines for distances such as that between New York and Chicago, it seems clear that their interest in this subject is very great.

The actual progress made in the communication field, including the extension of service across the Atlantic has been outstanding in its significance and perhaps unparalleled in any other similar period of time. I thought it would be interesting to outline briefly the trends of development in the two arts, as they now appear, to establish some comparisons, and to indicate some possibilities of development.

At the Midwinter Convention of the American Institute of Electrical Engineers, held in Philadelphia, which some of you

* Presented at a meeting held Thursday, April 12, 1928.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

may have attended, there were a number of very interesting and important papers read on the subject of transmission of power to comparatively long distances.

The characteristics of the line considered in this important series of papers were as follows:

| | |
|---|---|
| Potential | 220,000 volts |
| Size of Conductor | 750,000 circular mils |
| Spacing of Conductors | 19 feet |
| Resistance per mile | .0782 ohms |
| Reactance per mile | .80 ohms |
| Susceptance per mile | .00000542 ohms |

The characteristic impedance and the propagation constant, as computed, are equal to—

| | |
|---|---|
| Characteristic Impedance | $383.7 - j18.7$ ohms |
| Propagation Constant | $0.000102 + j0.002085$ |

The impedance of a typical 220-kilovolt high tension line is therefore lower than that of the open wire circuits used in the communication art, the impedance of such circuits usually being about 600 ohms.

A line of this type, if used between New York and San Francisco, would have an equivalent loss of 2.7 TU. It would be an excellent talking circuit, even taking into account echo effects. Using the information as given by Mr. Murray in "Superpower System for the Region between Boston and Washington," it may be estimated that the cost of a line of this type would be about $100,000,000. If use were made of these twin circuits of the high tension type for communication purposes, three physical and one phantom channel could be established over these circuits. The carrying capacity of these four circuits would be 70,000 messages annually and the annual cost of the conductors alone would be $200 per message. The establishment of carriers over these same circuits would decrease somewhat the above very large and uncommercial cost per message.

In discussing the papers on power transmission and particularly the one read by Mr. R. P. Thomas, Dr. Kennelly brought out the fact that for lines of great length of the order of 500 miles, the deviation between the nominal $\pi$ of the line and the equivalent $\pi$ was quite important.

To quote Dr. Kennelly—

"In the case of Mr. Thomas's line, 500 miles long, the nominal $\pi$ of any one of the three line conductors has an appreciable error at 60 cycles per second, and has to be corrected by some process which takes the uniform distribution of capacitance into account. This is done in the paper by means of the equation at the foot of its third page, which has been shown by Mr. Thomas in an earlier page to be suitable for the purpose. An alternative method, preferred by the writer, is to form the equivalent $\pi$ of the lines, such that the electrical behavior of this $\pi$ according to Ohm's law, gives the same voltage, current and power at its terminals under the assigned conditions of load, as the actual lines with its distributed constants."

I thought that it might be worth while to carry further the suggestion made by Dr. Kennelly and determine for a 220-kilovolt line of variable length, having the linear characteristics indicated above, the constants of the equivalent diagrams. Some interesting conclusions are brought out in this way. Before showing you these diagrams, I should like to show the "power limits," so-called, of 220-K.V. lines of various lengths. Figure 1*a* (Figure 5 of the paper by Evans and Sels) [1] shows how this power limit decreases rapidly, reaching a value of about 125,000 kilowatts at 500 miles.

Figure 1 shows the illustration furnished by Dr. Kennelly in his discussion, showing the deviation between the nominal $\pi$ and the so-called actual $\pi$ of a transmission line 500 miles in length.

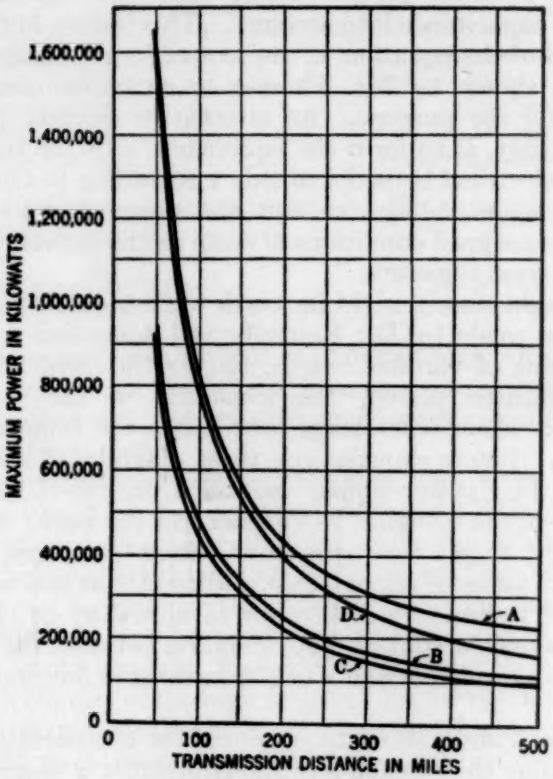
Figures 2 and 3 show the results of the computations made to determine the constants of the equivalent $\pi$ diagrams, the first figure showing the constants of the architrave impedance and the second showing the constants of the pillar impedance.

Some of the results are quite striking and I am sure will prove of interest. Referring first to Figure 2 it will be noted that the resistance component of the equivalent $\pi$ diagram reaches a maximum at about 500 miles, becomes zero for a line of 976 miles and reverses its sign, reaches a second maximum and becomes zero in value for a line of 2,280 miles

[1] "Power Limitations of Transmission Systems," *Trans. A. I. E. E.*, February 1924.

in length, approximately. The reactance component follows a similar course. It reaches a maximum for a line of, roughly, 800 miles in length, slightly over one-quarter wave-length,

FIG. 1a.




1a. Power Limits—220,000-Volt Line.

RELATION OF POWER LIMITS TO LENGTH OF TRANSMISSION LINE.

These diagrams are based on a transmission circuit employing 636,000 cir. mil. aluminum conductor with 21 ft. equivalent spacing, and with 220 k.v. maintained at the supply end. Curve "A" shows the maximum power limit with 60-cycle supply with unrestricted receiver voltage and condenser capacity. Curve "B" shows the maximum power limit with 60-cycle supply and 220 k.v. maintained at the receiver. Curve "C" shows the power limit at the envelope with 60-cycle supply and 220 k.v. maintained at the receiver. Curve "D" corresponds to Curve "B," except that the power supply is 25 cycles.

reaches zero for a line slightly longer than one-half wave-length, becomes a capacity reactance in changing sign, reaches a second maximum and crossing zero changes sign again for a length slightly in excess of one full wave-length.

The computations were carried out using the following relations:

(1) $$\text{Architrave impedance} = Z_0 \sinh Pl,$$

(2) $$\text{Pillar admittance} = \frac{\tanh \frac{Pl}{2}}{Z_0},$$

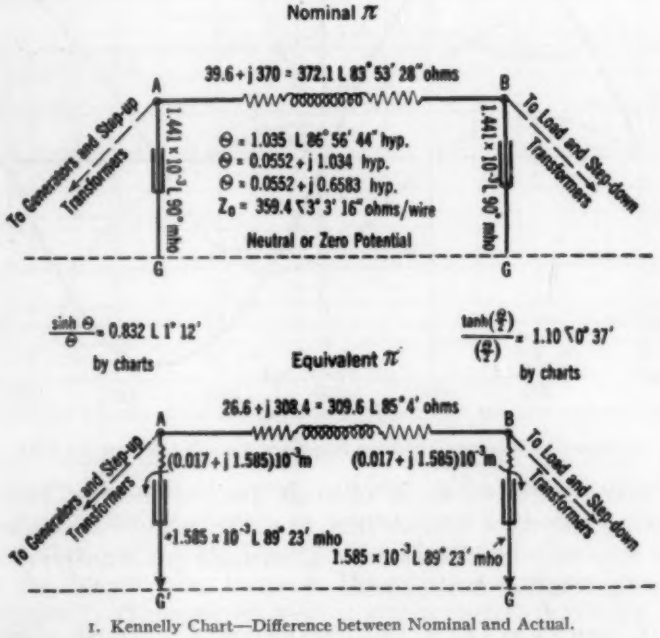
where

$Z_0$ = characteristic impedance of transmission line,

$P$ = propagation constant of transmission line per unit length,

$l$ = length of line.

FIG. 1.


Nominal π
39.6 + j 370 = 372.1 L 83° 53' 28" ohms
A
B
To Generators and Step-up Transformers
To Load and Step-down Transformers
1.441 × 10⁻³ L 90° mho
Θ = 1.035 L 86° 56' 44" hyp.
Θ = 0.0552 + j 1.034 hyp.
Θ = 0.0552 + j 0.6583 hyp.
Z₀ = 359.4 ∠ 3° 3' 16" ohms/wire
Neutral or Zero Potential
G
sinh Θ / Θ = 0.832 L 1° 12'
by charts
Equivalent π
tanh(Θ/2) / (Θ/2) = 1.10 ∠ 0° 37'
by charts
26.6 + j 308.4 = 309.6 L 85° 4' ohms
(0.017 + j 1.585)10⁻³ m
(0.017 + j 1.585)10⁻³ m
+1.585 × 10⁻³ L 89° 23' mho
1.585 × 10⁻³ L 89° 23' mho
G'

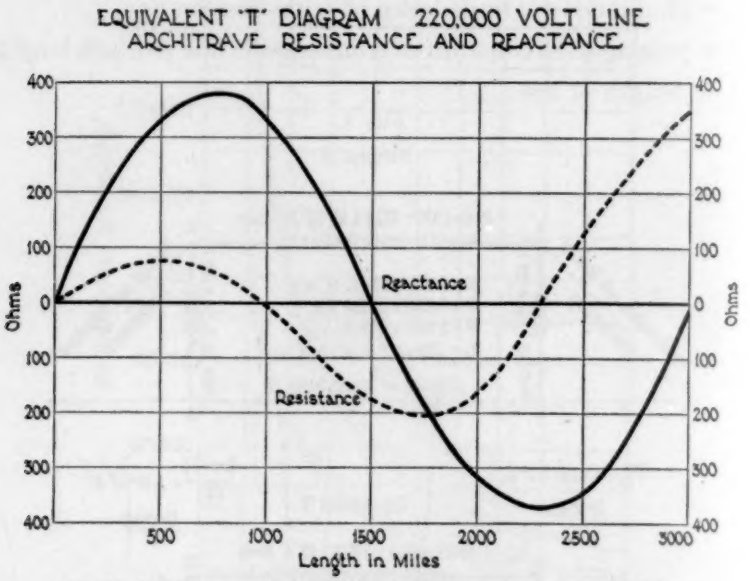
1. Kennelly Chart—Difference between Nominal and Actual.

The numerical values of $(P)$ and $(Z_0)$ for the particular 220,000-volt line, which has been taken as a basis for discussion in this paper, have already been given hereinabove.

The reversal of sign in the resistance component of the architrave impedance was unexpected to the writer and may prove a surprise to many other students. It might lead one to

suppose that transfer of electrical power can be made for a particular length of high tension line (976 miles actually for the particular line considered herein) without loss of real power in the line. This conclusion would be incorrect since the pillar impedance has a positive resistance component equal to 2,000 ohms for this particular line. The reversal of

FIG. 2.




2. Equivalent Diagram—Architrave Impedance, 500-Mile Line—220,000 Volts.

sign above referred to is of such general interest that the following reference is made here to make its derivation clear to those who may be interested. If formula (1) is amplified, the following relation is obtained:

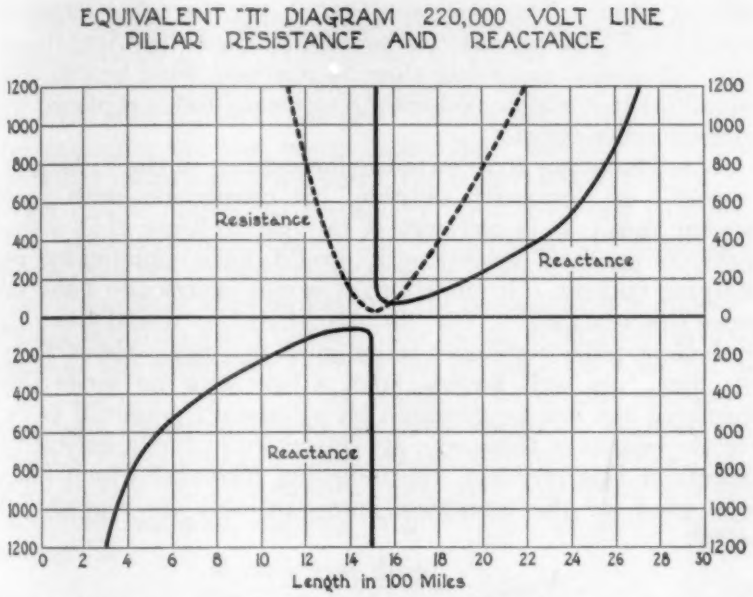
$$\begin{aligned} Z \operatorname{Sinh} Pl &= (R - jX)(\sinh al \cos bl + j \cosh al \sin bl), \\ &= (R \sinh al \cos bl + X \cosh al \sin bl), \\ &\quad - j(X \sinh al \cos bl - R \cosh al \sin bl). \end{aligned} \tag{3}$$

The resistance component is naturally equal to zero where

$$\begin{aligned} R \sinh al \cos bl &= - X \cosh al \sin bl, \\ \tan bl &= \frac{- R \sinh al}{X \cosh al}. \end{aligned} \tag{4}$$

The reversal of sign for the particular 220,000-volt line considered here is for a length of 976 miles, in excess of one-quarter wave-length, the wave-length as shown by the computed propagation constants being equal to 3,013 miles.

FIG. 3.




3. Equivalent Diagram—Pillar Resistance and Reactance—500-Mile Line—220,000 Volts.

The change in the reactance component of the architrave impedance is also of great interest. We are so used to thinking of line reactance in connection with high tension lines, particularly from the standpoint of such line reactance being the determining factor in the amount of power that can be physically transported over a transmission line, that it is somewhat of a surprise to find that it can be zero in amount or, perhaps what is still more interesting, it can actually become equivalent to a series capacity. It should not, of course, be concluded that the equivalent series line impedance is actually equal to zero for some particular length of line. This is not true as the two components of the architrave impedance do not reach zero value for the same length of line.

The results, as shown on Figure 3, are equally as interesting. It is assumed that the pillar impedance will be represented by two branch impedances, a resistance branch and a reactive branch. It is interesting to note that for a line having a length slightly in excess of one-half wave-length, the value of the pillar resistance becomes extremely small, of the order of only 25 ohms. The reactance branch, on the other hand, is represented by a capacity, as well known, for short lengths of line. However, for a line close to one-half wave length this capacity effect almost suddenly disappears and is replaced by an inductance effect.

It is customary to refer to the importance of the "charging current" or "capacity current" in connection with high tension lines. It is certainly of interest to know that a line close to one-half wave-length would have practically no charging current. In addition, it would practically have no series line reactance. On the other hand, it would have an equivalent pillar resistance quite small in value—about 23 to 25 ohms. As well known, such a line with no series line reactance can not be operated on a constant potential basis. For the benefit of those who are interested in the quantitative aspects of this problem, the following formulæ, which have been used for the numerical computations, are reproduced below.

$$(5) \qquad \text{Tanh}\frac{Pl}{2} = \frac{\sinh al + j \sin bl}{\cosh al + \cos bl},$$

where $(a)$ and $(b)$ indicate the components of the propagation constant $(P)$.

The values of the resistance and the reactance of the pillar impedance, considered as a two-branch impedance of a resistance in parallel with a reactance, may be obtained from the following:

$$(6) \qquad \text{Resistance} = (R^2 + X^2)\frac{\cosh al + \cos bl}{R \sinh al - X \sin bl},$$

$$(7) \qquad \text{Reactance} = -j(R^2 + X^2)\frac{(\cosh al + \cos bl)}{X \sinh al + R \sin bl}.$$

The reactance as given by relation (7) reaches infinity (with consequent disappearance of the "charging current)"

where

$$X \sinh al + R \sin bl = 0,$$

$$\sin bl = -\frac{X}{R}\sinh al. \tag{8}$$

LIMITATIONS DUE TO STABILITY OF ROTATING APPARATUS.

The figures (2 and 3) descriptive of the series and shunt characteristics of the equivalent $\pi$ circuits of high tension lines of various lengths must be read, of course, in the light of practical possibilities of the art. On account of the fact that the generator at the power house and the motor at the generator include rotating parts, the transmission of electrical power can be carried with stability up to a certain length of line. At the present stage in the development of the art, this length does not exceed one-quarter of a wave-length. In the case of a typical 220-kilovolt line, the wave-length is approximately equal to 3,013 miles. (For check, refer to computed value of the imaginary term in the propagation constant as given above.) The limit of stability, as usually accepted, would not therefore exceed 750 miles, roughly. Noteworthy progress has lately been made in this direction. Wagner and Sels (*A. I. E. E. Transactions* 1928, page 101) show that the maximum angle of stability is given by the following relationship:

$$\tan \phi_0 = \frac{W_b + W_a}{W_b - W_a}\tan \phi_1, \tag{9}$$

where

$\phi_0$ = maximum angle of stability,

$\phi_1$ = angle of vector $\dfrac{\text{Sinh } Pl}{Z_0}$,

$W_a$ = stored mechanical energy at generating end,

$W_b$ = stored mechanical energy at receiving end.

A method of extending the maximum angle of stability is described below as the "neutralization method," which is believed to be new. Since the angle of stability, as given by the above relation, depends upon the value of the angle $\phi_1$ of the line, a decrease in the hyperbolic angle per unit length of

line will naturally result in the same relative stability for a longer length of line. It is possible, for instance, by providing for 50 per cent. neutralization of the line constants, to double the wave-length from 3,013 to 6,026 miles and, correspondingly, increase the limit of stability from 750 miles to somewhere near 1,500 miles.

The limitation just described as to the length of transmission line which offers possibilities of stable operation is distinctive of the power art. In the communication art no such limitation holds. A cable circuit, such as ordinarily used, between Philadelphia and Wilmington has a length equal to two wave-lengths. A line between Philadelphia and Chicago has the equivalent of 45 wave-lengths, when speech frequencies of the order of 1,000 cycles are being transmitted over them.

### POWER TRANSFER LIMITATIONS—PRESENT ART.

Important contributions have recently been made to this subject. Present power transmission practice calls for a synchronous condenser at the receiving end of the transmission line, not only for purposes of voltage control, but also for the purpose of increasing the power transfer over a line operating at a given constant potential. It has been shown that the power limit ($P_r$) is given by

$$P_r = E_r \frac{(E_s - E_r \cos \theta)}{Z}, \tag{10}$$

where

$E_s$ = generator potential,

$E_r$ = receiving end potential,

$Z$ = series impedance of line.

(See Steinmetz, "Alternating Current Phenomena," page 102.)

The above formula admittedly holds for short lines only. For long lines, the following formula, as given by F. Terman (*A. I. E. E. Transactions*, 1926, page 1091) is reproduced hereunder.

$$\text{Maximum Power} = \frac{E_r\{E_s \cos(\phi-\beta) - aE_r \cos(\alpha-\beta)\}}{b}, \tag{11}$$

where

$\alpha$ = angle of vector $a$ or (cosh $Pl$),

$\beta$ = angle of impedance $b$ or ($Z_0$ Sinh $Pl$),

$Z_0$ = characteristic line impedance,

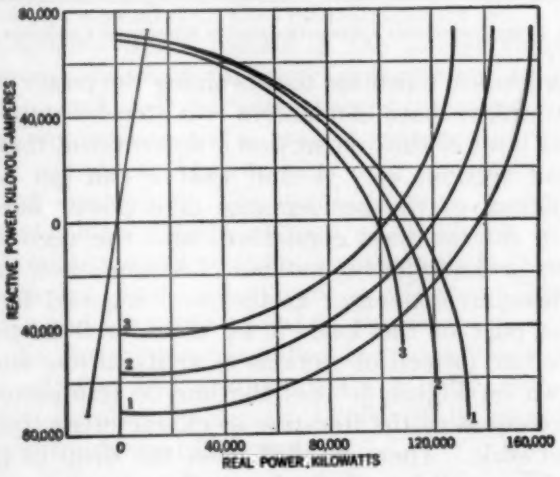
$P$ = propagation constant of line per unit length,

$l$ = length of transmission line,

$\phi$ = angle by which the sending voltage leads the receiving voltage.

It is interesting to note here that the denominator in the above formula is the architrave impedance of the equivalent $\pi$ circuit of the transmission line. Values for both the resistance and the reactance components of the architrave impedance have been computed for various lengths of 220,000-volt high

FIG. 4.

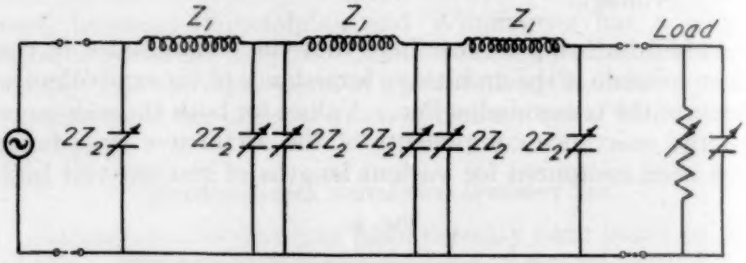



4. Philip's Chart—Circle Diagram.

tension line and shown on Figure 2. The figure referred to will therefore prove of interest from the standpoint of applications of formula (11) of maximum power to particular cases. Power limits may also be obtained by the famous Circle Diagram (see Figure 4), due to R. A. Philip (see *A. I. E. E.*

*Transactions*, 1911, and the symposium papers read at the Midwinter Convention of the A. I. E. E., 1924). Since there is a power limit to a line of given length using a synchronous condenser at the receiving end, a great deal of real interest has been aroused by the suggestion of Mr. Baum that, in addition to the terminal synchronous condenser, the use of intermediate synchronous condensers would result in increasing the power limit of a line and incidentally in increasing its stability.

FIG. 5.




5. Power Transmission System—Intermediate Synchronous Condensers.

The procedure now used for obtaining the power limit of a line with intermediate condensers is a step-by-step method. The power limit of the first section is determined, then that of the second section, etc. I find that I can get a clearer mental picture of the performance of a power line with a number of intermediate condensers and the need for such condensers in the following manner. Assume that, instead of the synchronous condenser at the receiving end being considered as part of the load, it be considered as part of a composite line formed of sections of artificial line and actual line, shown on Figure 5. Let the line be terminated by an impedance equal to the iterative or characteristic impedance of the network. Then, in that case, the drop in potential along the line will be relatively small and will be given by $e^{-Pl}$. For a line with no synchronous condensers, this would be equal to about 5 per cent. on a 500-mile line and would be somewhat larger, although still small, for the case where the usual amount of synchronous capacity is added. Assume, as the load changes, that some kind spirit changes simultaneously the values of the capacities of the condensers bridged across

the line so that the load is still equal to the iterative impedance of the network. In practice, the kind spirit just referred to would be the voltage regulator associated with the synchronous condenser. This may require, for very light loads, that the synchronous condensers be operated as reactances; and, finally, they may be sufficiently large reactively to wipe out the capacity of the line. Then, in such a case, there will be very small, if any, drop of potential at the receiving end, with extremely wide changes in load. The line is then "regulated."

The interesting question comes up—what is the heaviest load such a line will carry? The circle diagram method can of course be used on a step-by-step basis, as already referred to. There is another method which shows some interesting results. It can be shown that, if capacity is added, the iterative impedance of the network follows a curve as shown in Fig. 6 below. It is infinity, of course, for $C = 0$, reaches a minimum, then increases and reaches infinity again. A further increase in capacity stops all power transfer. This is the cutoff point of the line, as we call it in the communication art. The value of the capacity which results in the lowest value for the iterative impedance is inversely proportional to the series impedance included between successive condensers. By installing condensers at a greater number of points, we gradually approach the condition of a line with uniformly distributed constants. The total amount of synchronous capacity can take a value as high as we please, in fact can approach infinity when added at a sufficiently large number of points—leaving aside all questions of cost. The second interesting and important point in this connection, however, is this: As the capacity installed increases, the attenuation constant of the line also increases rapidly and, in fact, approaches infinity ultimately. This will be clear by reference to the fundamental formula

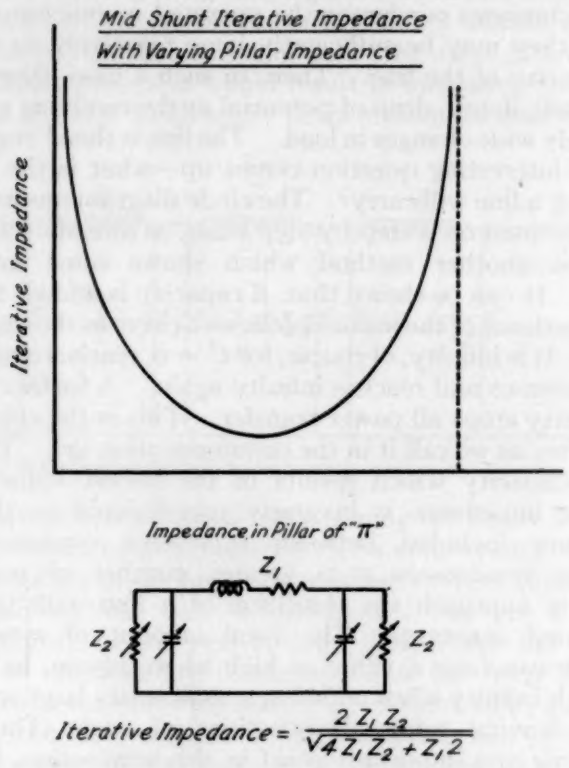
$$a = \frac{R}{2}\sqrt{\frac{C}{L}}, \tag{12}$$

when $C$ is given gradually increasing values.

It is clear, therefore, that increased power transfer, through the use of synchronous condensers located at intermediate

points along the line, when designed for maximum power transfer, results in decreased efficiency of transmission.

FIG. 6.


Mid Shunt Iterative Impedance
With Varying Pillar Impedance
Iterative Impedance
Impedance in Pillar of "π"
$Z_1$
$Z_2$
$Z_2$
Iterative Impedance = $\frac{2 Z_1 Z_2}{\sqrt{4 Z_1 Z_2 + Z_1^2}}$
Note: Assume that the phase angles of $Z_1$ and $Z_2$ differ by 180°

6. Midshunt Iterative Impedance—Varying Pillar Impedance.

**EFFICIENCY OF LINE TRANSMISSION AS RELATED TO POWER TRANSFER.**

One question which, perhaps, has not received as much attention as the question of power transfer limitation is that of efficiency of transmission. The use of synchronous condensers, both at intermediate points along the line and at the receiving end, when used for the practical purpose of increasing the power transfer over a given high tension line, is

electrically equivalent to adding capacity at intermediate points along the line and at the receiving end. This will be clear by referring to the circle diagram (Figure 4) which, for maximum transfer of real power, shows leading kilovolt amperes required as reactive power. The same situation holds at intermediate synchronous condenser stations. The question properly arises: what is the effect upon efficiency of transmission of the arrangement proposed to secure increased power transfer? The study of this question shows that a loss in efficiency of transmission is the result, as perhaps might have been expected. For instance, the 500-mile line has the following efficiency:

| | Transmission Efficiency % |
|---|---|
| 1. With synchronous condensers arranged for voltage control purposes only | 95 |
| 2. With synchronous condenser at receiving end, arranged for maximum power transfer | 89 |
| 3. With synchronous condensers at intermediate point and also at receiving end. (Midway location.) | 77 |

### DISCUSSION OF GENERAL METHODS FOR SECURING HIGH EFFICIENCY IN TRANSMISSION.

The above situation leads immediately to the following general question. Under what conditions can high efficiency of transmission be obtained? It should, of course, be clearly understood that under certain conditions it may be desirable, from an economical point of view, to operate a line at a point lower than its highest possible efficiency. Notwithstanding this, the inquiry as to possible maximum limits of transmission efficiency loses none of its interest. This is particularly true in case it is found economically practicable to transport electrical power to greater distances than now contemplated. It is well known that the attenuation constant ($a$) of a line is given by

$$a = \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}, \tag{13}$$

where $R$, $C$, $L$ and $G$ are, respectively, the resistance, capacity, inductance and the dielectric conductance constants of the line. The above relation is known to hold where the reactive

components of the line constants are large as compared with the resistance components. In the case of the typical 220-kilovolt line, the series reactive component is ten (10) times larger than the resistance component, and power engineers hold that $G$ is negligible. The above relation therefore holds and may be expressed still more simply by the relation

$$a = \frac{R}{2}\sqrt{\frac{C}{L}}.$$

To obtain high transmission efficiency it is necessary to make $(a)$ as small as possible.

In the communication art, the trend of progress has consisted in increasing $(L)$. A second method would consist in decreasing $(C)$. A third method would consist in reducing equally $(C)$ and $(L)$ or reducing $(C)$ more than $(L)$. Referring to the second method, we can not carry this out at the present time in the communication art, as it would require a device which has the exact opposite characteristics to that of a capacity for the entire range of frequencies involved in the band of intelligible speech. It is possible, however, to apply it in the power art, since single frequency transmission only is involved. Strange as it may seem at first sight, the present tendency in the power art is in the opposite direction; The tendency is toward increasing $(C)$ as already explained, with the resulting disadvantage of loss in transmission efficiency. But, as already stated, the increase in power transfer is a justification for this method.

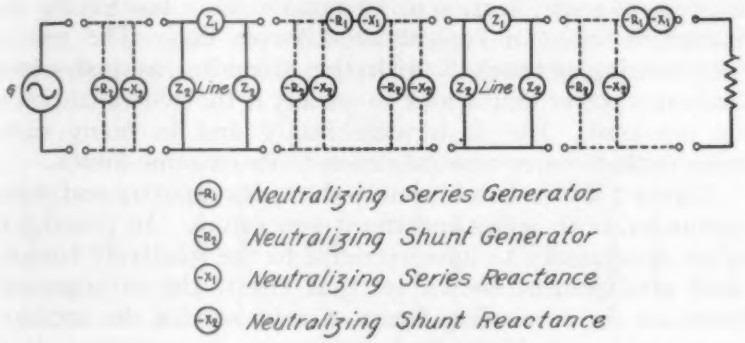
### METHOD OF NEUTRALIZING NETWORKS.

The second and third methods for obtaining high efficiency of transmission with increase in power transfer also lead to the arrangement shown on Figure 7, which is believed to be new. As shown on this figure, networks consisting of series condensers and shunt reactances with series and shunt, generators are bridged at intermediate points along the line, thus "neutralizing" the series line and shunt capacity characteristics of the line. The neutralization may be more or less complete, depending upon the economic factors involved which will not be discussed here. There are several physical

and technical questions that are of such general interest that it seems worth while to outline them briefly.

The first difficulty which must be met is that of series resonance. This difficulty can be overcome by installing the series condensers at sufficiently frequent intervals. I find that the most desirable arrangement consists in providing

FIG. 7.




7. Transmission System with Neutralizing Networks.

half-spacing at both the power house and substation ends and full spacing at intermediate points where neutralizing networks are installed. With this arrangement in effect, the necessary number of neutralizing networks is given by the formula shown below if it is desired to reduce the increase due to series resonance to less than $c$ times the line potential.

$$n = \frac{P}{2E^2} \cdot pL \cdot \frac{1}{2c}.^2$$

As might have been expected, the spacing must be more frequent, the greater the power transfer desired. Using the physical data as to line constants, a practical spacing seems to be a neutralizing network for every 150 miles of high tension line. The second question that must be answered is: how can the use of "neutralizing networks" be worked out to secure high transmission efficiency combined with high transfer of power? It can be very readily shown that the

[2] $P$ is expressed in watts and $pL$ = total linear reactance of the line.

method of "neutralizing networks" has no power limit if the underlying fundamental idea is carried through to its extreme possibilities which, of course, include neutralization of the resistance as well as the reactive components of the line. Neutralization of the resistance components of a high tension line in the power art would be equivalent to the use of amplifiers in the communication art. So far as the limited study made by the writer indicates, there seems to be no real field for this type of neutralization up to 3,000 miles of line having the characteristics of a typical 220-kilovolt line. The use of "neutralizing networks" with the exception as just noted eliminates power limitations physically if the neutralization is 100 per cent. But it is unnecessary and in many cases undesirable to carry neutralization to its extreme limits.

Figure 7 shows, in addition to the series capacity and shunt reactances, both series and shunt generators. In practice it seems unnecessary to have recourse to the relatively complicated arrangement shown on that chart, the arrangement shown on the succeeding figure, 8, representing the arrangement which will likely find application in practice. It is interesting to show, however, that the neutralizing series power generators can be entirely eliminated and resistance neutralization obtained by means of shunt generators only. If $R$, $C$, $L$ and $G$ represent, as heretofore, the characteristics of the "equivalent" line after neutralization, then, in order that power may be transmitted without any "net" losses between power house and substation, it is necessary and sufficient that the attenuation constant of the "equivalent" line, composed of sections of actual line and of sections of neutralizing network, shall be equal to zero. This condition requires that the following relation be satisfied:

$$\frac{R}{2}\sqrt{\frac{C}{L}}+\frac{G}{2}\sqrt{\frac{L}{C}}=0,$$

or

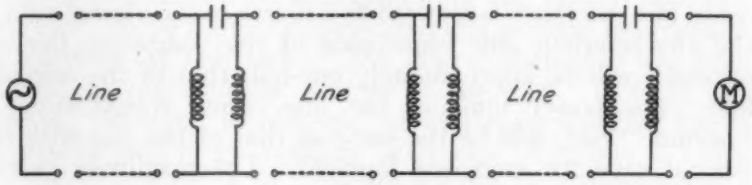
$$G=-R\left(\frac{C}{L}\right).$$

The kilowatt capacity of the shunt generator required will be obtained approximately by $E^2Gl\times 10^{-3}$, where $l$ is the spacing

desired between neutralizing generators. Accurate computations can be carried out by determining the constants of the equivalent $\pi$ of a length ($l$) of the line and computing a value for a negative shunt resistance such that the total attenuation of the equivalent $\pi$ diagram, including line and corresponding neutralizing network, is equal to zero.

Referring now to the simpler arrangement shown on Figure 8, it may be shown how high power transfer may be obtained. On this chart, only reactance neutralization elements are shown. Since, as already indicated, the transfer of power is inversely proportional to the architrave impedance, $Z_0 \text{ Sinh } Pl$

FIG. 8.




8. Transmission System with Reactance Neutralizing Networks.

of the equivalent $\pi$ diagram, the use of neutralization networks, of the type shown on Figure 8, will permit greater transfer of power on account of the possibility it affords of reducing both of the terms, $Z_0$ and Sinh $Pl$, of the architrave impedance $Z_0$ Sinh $Pl$. It may be mentioned here, as a matter of real interest, that where $Z_0$ (for the composite line illustrated on Figure 8) is maintained at the same value as the characteristic impedance of the line without neutralizing networks, then the transmission efficiency of the composite line will be practically the same as that of the actual line not equipped with neutralizing networks. The power limit, however, of the composite line will be greater on account of the reduction in the value of Sinh $Pl$.

In order to establish as broad and as simple a comparison as possible between the two methods of increasing the power limit of a line—between that which uses an increase in the equivalent capacity of the line and that which uses neutralization of the series line reactance and of the shunt capacity reactance of the line, the following simplified case is submitted.

Assume an actual line of length ($l$) and determine the power limit of the line, restricting the use of synchronous condensers at the substation end to voltage control purposes only. Suppose we wish to double the power transfer. We can attain this objective by increasing fourfold the natural capacity of the line. The transmission efficiency of this same line will be equal to the square of the transmission efficiency of the actual line. As an illustration, if the efficiency is 85 per cent. for the original simple line, the efficiency of the line with increased capacity will be $0.85 \times 0.85 = 0.7225$. This efficiency will obtain provided, as assumed, the load at the substation is equal to the characteristic line impedance.

If, now, use is made of the neutralization method and the series line reactance is reduced to a fourth of its original value, the characteristic line impedance of the composite line so obtained will be approximately one-half that of the original line. The power limit of the line, when transmitting a "normal" load, will be the same as that of the line with its normal capacity increased fourfold. The maximum power limit of the line equipped with neutralizing networks, however, will be much greater than that of the line equipped with intermediate synchronous condensers for the reason that the architrave impedance of the equivalent $\pi$ diagram will be considerably smaller. This point is almost obvious since, in the expression $Z_0 \operatorname{Sinh} Pl$ for the architrave impedance, the term $Z_0$ has exactly the same numerical value for the two solutions under discussion but the term $\operatorname{Sinh} Pl$ is considerably smaller for the system using neutralizing networks. The value of the propagation constant ($P$), as already indicated, is equal to $(a + jbl)$, and the wave-length factor ($b$) is equal to $\sqrt{LC}$, approximately. In the solution which adds capacity to the line the wave-length of the equivalent line is decreased one-half, while in the solution utilizing neutralizing networks the wave-length is twice as large as that of the original line. It therefore follows that the power limit of the line equipped with neutralizing networks is considerably greater than that of the line equipped with bridged condensers, when these two systems are adjusted to have equal characteristic impedances and equal attenuation factors. Furthermore, the transmission efficiency of the method using neutralizing networks

will be higher than that of the method using synchronous condensers for all loads in excess of the "normal" load. This is due to the fact that the series impedance interposed between the power house and the substation is smaller for the solution using neutralizing networks. The numerical value of this impedance is given by

$$Z_0 \operatorname{Sinh} Pl = \sqrt{R^2 + X^2}\,\sqrt{\operatorname{Sinh}^2 al + \sin^2 bl}$$

and we have already shown that $(b)$ is considerably smaller for the solution using neutralizing networks as compared with the solution which "adds" capacity to the line.

A complete analysis of the relationship between power transfer and transmission efficiency for the various solutions discussed above is quite complicated and perhaps unnecessary to consider at this time. The above discussion has been limited to the simplest aspects of the case. It is of real interest, however, to indicate one of the outstanding merits of the method of neutralizing networks. Consider a transmission line of length $(l)$. Such a line can be represented by a $\pi$ diagram. We can, by adding impedances of the correct sign, completely neutralize the two pillar impedances. Such a procedure may require reactances at both ends of the line and, in addition, resistance compensation or generators. If this has once been done, we have the equivalent of what is usually designated in the transmission art as a "short line." The transmission characteristics of such a short line are well known and completely covered in standard text-books. It is known, for instance, that the power limit of a short line is definitely given by

$$P_r = E_r \frac{E_s - E_r \cos\theta}{Z}.$$

In the case of transmission lines operated at constant potential $E_r = E_s$ and the expression for the power limit in this case is

$$P_r = E_s^2 \frac{1 - \cos\theta}{Z}.$$

It has also been shown in standard text-books that if $Z = R + jX$, then the power limit of the line reaches a maximum when

$$X = \sqrt{3}R.$$

(Steinmetz, Alternating Current Phenomena, pages 102 and 103). When and if the above relationship can be satisfied, then

$$P_r = E_s^2 \frac{1 - \frac{R}{Z}}{Z} = \frac{E_s^2}{4R}$$

and it is possible to transmit over an alternating current system the same amount of power as over a direct current system operated at the same potential, except for the comparatively small losses required for pillar resistance neutralization. In the case of short lines, the relation between $X$ and $R$ is far from satisfying the optimum condition $X = \sqrt{3}R$, as the ratio $\frac{X}{R} = 10$, approximately, for typical 220,000-volt lines. It is possible, by reference to Figure 2, showing the characteristic resistance and reactance values for lines of various lengths to see readily that for 220,000-volt lines it is not practicable to realize the optimum condition for maximum power transfer. However, if the system of neutralizing networks is applied and series capacity reactance is added to the line, it is possible to realize the condition for maximum power transfer within wide ranges of line length.

#### COMPARATIVE POWER TRANSFER AND EFFICIENCY FIGURES FOR HIGH VOLTAGE LINES USING INCREASED LINE CAPACITY OR REDUCED LINE CONSTANTS.

The above brief description gives an idea of the comparative characteristics of high voltage lines which have capacity added in shunt, approximating the condition of synchronous condensers added at intermediate points along the high voltage line and of lines equipped with neutralizing networks. It is known, of course, that the power limit of a line equipped with static capacity, in some form, bridged across the line is not exactly the same as the similar limit for lines provided with synchronous condensers. Nor is the transmission efficiency the same in both cases since synchronous condensers consume real energy while, with static condensers, the corresponding consumption of energy is negligibly small. The performance analysis of lines equipped with synchronous condensers at a great number of intermediate points is quite complicated and, for that reason, the

simpler case of bridged static condensers has been considered here.

Quantitative data as to power transfer and transmission efficiency have been worked out for a 500-mile, 220,000-volt line for the following two cases:

1. A 220,000-volt line with bridged static condensers at a sufficiently large number of points, increasing the normal capacity of the line four times.
2. A 220,000-volt line with series static condensers, reducing the series reactance of the line, 0.80 ohms per mile, to 0.20 ohms per mile, or to a quarter of its original value.

The computed characteristics of these two lines would be as follows:

| | 1 | 2 |
|---|---|---|
| (*a*) Characteristic Impedance in Ohms. | 191.85 − j9.35 | 195.6 − j36.88 |
| (*b*) Pillar Resistance in Ohms..... | 645.2 | 1918 |
| (*c*) Pillar Reactance in Ohms..... | − j112.7 | − j776 |
| (*d*) Propagation Constant..... | 0.0002 + j0.004170 | 0.0002 + j0.00106 |
| (*e*) Architrave Impedance in Ohms.... | − 1.44 + j168.4 | 36.57 + j67.69 |

Solutions 1 and 2 were worked out so as to obtain the same characteristic impedance and the same attenuation factor so far as practicable. The power transfers for these two solutions, for normal loads equal to the characteristic impedance of the line, are also practically the same for these two solutions:

Line with bridged capacity = 205,000 K.W.
Line with neutralized networks = 195,000 K.W.

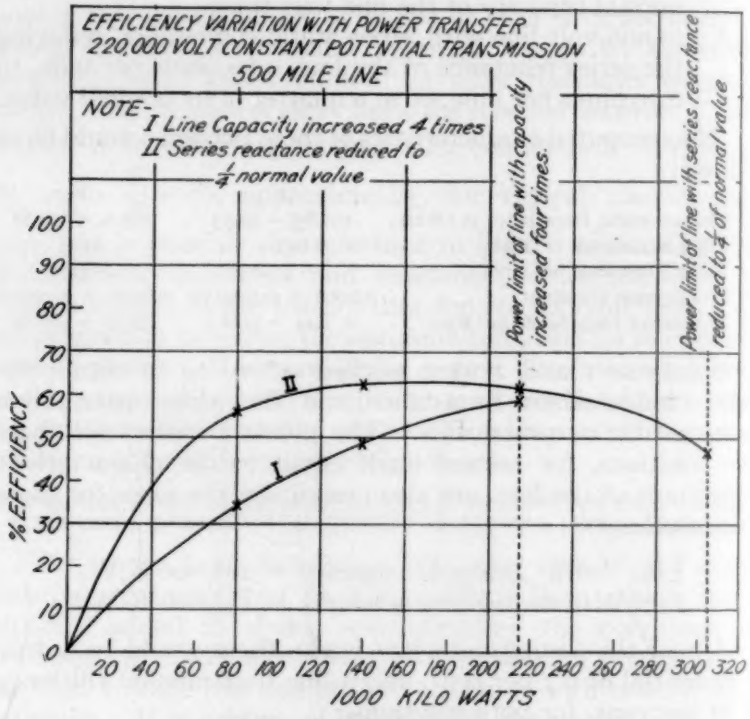
Under the assumptions just made, there would be a drop in potential of 9.7 per cent. and a line transmission efficiency of 81 per cent. for both solutions.

In the case of the normal line the corresponding power limit is 113,000 kilowatts.

The important differences between these two solutions obtain in conjunction with the maximum power limits and the transmission efficiency when operating on a constant potential basis. The maximum power limit of the high capacity line is 215,000 kilowatts. The maximum power limit of the line equipped with neutralizing networks (Solution 2) is 305,000 kilowatts. The efficiency of transmission for the high

capacity line transmitting 215,000 kilowatts is 59.6 per cent. The efficiency of transmission of the line equipped with neutralizing networks, transmitting the same power, is 62 per cent. It should be stated here that all figures given above are for the transmission line only, disregarding the limitations as to the maximum amount of power that can be transmitted

FIG. 9.




9. Efficiency Variation with Power Transfer.

due to the impedance of the generating apparatus, and the effect of the step-up and of the step-down transformers. These could easily have been included, and the methods for including them are well known but were omitted for the sake of simplicity.

Transmission line efficiency figures were computed for a number of different loads at the substation end. The results of these computations are shown on Figure 9, which shows at a

glance the advantage of the use of the system using neutralizing networks over that using bridged capacity across the line.

LIMITATIONS IN POWER LIMITS—LINES WITH BRIDGED CAPACITY AT INTERMEDIATE POINTS ALONG TRANSMISSION LINE.

It might be thought at first sight that if bridged capacity is added at sufficiently frequent intervals, the power limit of such a line might increase indefinitely. A closer view of this situation shows that the increase in attenuation resulting from the capacity added to the line, definitely limits the power transfer over a high tension line operated at a given potential with a "normal" termination equal to the characteristic impedance of the line.

The study of the quantitative value of this limit, for the case of distributed capacity, is extremely interesting. It shows that the value of this limit is given by

$$\text{Power Limit} = \frac{E^2}{2lR} \cdot \frac{1}{e}\left(1 + \frac{pL}{\sqrt{R^2 + p^2L^2}}\right),$$

where, as before, the significance of the symbols is

$l$ = length of line,
$R$ = resistance per mile,
$pL$ = reactance per mile,
$e$ = basis of Naperian logarithms.

It is surprising to find that the maximum power limit is quite high; it is equal to 454,000 kilowatts, approximately. This compares with a figure of 113,000 kilowatts for the normal 220,000-volt line operated under similar conditions. This high limit is obtained for an optimum value of distributed line capacity given by the following formula:

$$\sqrt{pC} = \frac{1}{l\sqrt{2}(\sqrt{p^2L^2 + R^2} - pL)}.$$

The optimum value for the capacity ($C$) thus decreases with length of the line ($l$). Another important conclusion that can be immediately drawn is that, when a high tension line is long enough to have a total attenuation of 0.50 in

numerical value, the addition of "bridged" capacity will decrease its power limit instead of increasing it.

The above conclusions, as definitely stated, refer only to transmission systems with bridged capacity. It seems also evident that, notwithstanding how closely intermediate synchronous condensers may be placed upon a given transmission line, there will be a maximum power limit to such a line. The second interesting and important conclusion is that the advantage that may be expected through the use of synchronous condensers will be less and less effective for very long lines. It would be interesting to have this second point established by direct analysis rather than by inference.

## POSSIBILITIES OF TRANSCONTINENTAL TRANSMISSION OF POWER.

In the above detailed outline of the possibilities of the transportation of electric power, a 500-mile line was taken as a basis of discussion. It should be understood, of course, as already stated, that the procedure consisting in the use of alternate sections of transmission line and neutralizing network can be carried out for any distance. Transportation of electric power may thus be physically carried out across the continent of the United States. The neutralizing networks, as shown on the drawings, may be partial or complete. The length of each section of transmission line may also differ, depending upon economical conditions obtaining in each specific case. Assuming, for illustration, the distance of 3,000 miles and that the pillar neutralization is complete and is provided for at every 500 miles, while the architrave neutralization is partial and is provided for at every 100-mile interval (in order to limit the potential rise along the line), it is readily seen that the corresponding equivalent $\pi$ network of the 3,000-mile line will be equal to that of a 500-mile line if the architrave neutralization is 5/6 complete. Therefore, the amount of power that can be transmitted over the 3,000-mile line will be equal to that which can be transmitted over a 500-mile line. The cost of transportation will, of course, be greater, since the investment in transmission line conductors and in neutralizing equipment will be correspondingly greater.

The above statement assumes, of course, that neutral-

ization has been provided, not only for the reactance component, but also for the resistance component of the architrave impedance. Resistance neutralization requires the use of either series or shunt generators spaced at intervals of, roughly, 500 miles. The resistance neutralization can be avoided by raising the potential of transmission from 220,000 volts to 330,000 volts and providing a compound line, substantially, as described above, with provision for

(*a*) Complete pillar susceptance neutralization.
(*b*) Partial architrave reactance neutralization.

To show more definitely the practical application of the system disclosed herein, for transcontinental transmission, the following data are submitted. The increase in the transmission potential will require raising the outside diameter of the transmission line conductors in the ratio of 3 to 2 (corresponding to ratio of potentials, 330,000 to 220,000 volts) in order to avoid corona. The line conductors can, however, be in hollow copper, avoiding in this manner the use of extra metal in the line. The spacing of the conductors will have to increase practically in the same proportion, thereby increasing the line reactance constant per mile. Assuming that the resistance per mile of the more widely spaced hollow copper conductors is the same as that of the typical 220,000-volt line described hereinabove, and carrying out the neutralization of the series line reactance to the point where maximum power limit is realized for the system as a whole, the characteristics of this "compound" line would be

| | |
|---|---|
| Resistance per mile | .0782 ohm |
| Reactance ($\sqrt{3}$ times the resistance) | .1360 ohm |
| Susceptance per mile | 0.0000 mho |

The architrave impedance of a 2,000-mile line, constructed in accordance with the above specifications, would be

$$\text{Resistance} = 234.6 \text{ ohms},$$
$$\text{Reactance} = 408.0 \text{ ohms}.$$

The power limit ($P$) of this line would be

$$P_{\max.} = \frac{(330{,}000)^2 \times 10^{-3}}{4 \times 234.6} = 116{,}000 \text{ kilowatts, approximately.}$$

The above limit is practically the same as that of a 500-mile line, operated at 220,000 volts, constant potential, not equipped with neutralizing networks. It is thus seen that a system of "compound" conductors could be built, connecting the great power centers in the United States, which would allow power transfer of the order of 100,000 kilowatts, or more, from end to end, up to a distance of 3,000 miles, when operated at 330,000 volts and equipped with neutralizing networks substantially as described.

### APPLICATION OF NEUTRALIZING NETWORKS TO COMMUNICATION CIRCUITS

The application of neutralizing networks to communication circuits also offers a wide and interesting field. It was noted that in power transmission application reactance neutralization was important. In the communication art, the reverse holds true. Resistance neutralization in the form of $\pi$ or $\tau$ networks will undoubtedly be found useful. It is also possible that phase correction may be obtained. Such an application would prove of real importance on very long cables.

Such neutralization would represent the equivalent of amplification, as at present so successfully carried out in communication practice.

The application of neutralization to communication circuits is so complex in character that it will not be considered further in the present paper.

# THE COST OF LIGHTING INDUSTRIAL BUILDINGS.

BY

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WITH the advent of the industrial age, man was forced indoors for the protection of his work from the ravages of the elements. This change of work-place was made regardless of the inadequacy of the natural lighting within his crude building, and regardless of the expense and limited controllability of the artificial light-sources at his command. As time progressed, buildings were constructed with larger and larger windows. Finally, in order to obtain a higher and more uniform intensity of illumination upon the work-plane, buildings were constructed with high continuous windows in the walls and elaborate windows in the roof.

Within the last few decades, artificial light-sources have been made dependable, much less expensive than formerly, and highly controllable.

As a consequence, most industrial and commercial buildings are equipped for both natural and artificial lighting. In uncongested districts one-story buildings constructed with monitor or sawtooth windows in the roof employ artificial lighting for a relatively small part of the usual work-hours of the day; whereas multi-story buildings in congested districts employ artificial lighting many so-called daylight hours.

A habit has been formed of using daylight in all types of buildings regardless of the fact that in certain places artificial light could better fill the requirements. Many years ago Dr. M. Luckiesh began emphasizing the undue persistency of this "daylight habit" in lighting museums and other places. Later, in order to bring the economic aspect of the matter forcefully to the attention of architects, engineers and the public, Dr. Luckiesh and the writer [1] investigated the relative

[1] "The Cost of Daylight," M. Luckiesh and L. L. Holladay, *Trans. I. E. S.*, 18, 1923, p. 119.

cost of natural and artificial lighting in residences, hotels and art museums, and found their costs quite comparable.

With the increasing economic stress of industrial competition and the advancement of the lighting art, it appears desirable to determine the most economical type of building from a lighting viewpoint, and to determine the most economical conditions under which it may be operated. Therefore, the purposes of this investigation are to devise ways and means of computing the complete cost of lighting industrial buildings, to determine from a number of suitable types of buildings for a given industry, which one can be most economically lighted, and to ascertain the most economical conditions of maintenance and operation.

### INVESTMENT COST OF NATURAL LIGHTING EQUIPMENT.

Natural light is free outdoors, but when delivered indoors it has a fairly definite cost. Upon consideration, it is apparent that windows, awnings, shades, curtains, light-courts, a more expensive type of building to admit more light and distribute it better, certain losses of heat incident to windows, and the heating equipment to supply these losses are avoidable expenses directly chargeable against natural lighting.

Windows have a psychological value in permitting one to see out; however, in many industrial buildings this advantage is sacrificed by glazing the windows on the level of the workmen's eyes with "obscuring" glass. Windows may be a disadvantage in summer in admitting and trapping heat; however, this only reduces the pleasantness of the building somewhat without increasing its cost unless measures are taken to remove the heat.

In order to have a definite basis for computing the cost of natural lighting, a standard procedure which seems logical and fair has been adopted and followed throughout this investigation. The cost of the standard building of given type and size with all of its natural lighting equipment, including windows, light-courts, heating system, etc., is computed. Then the cost of an equally satisfactory building of the same size, of analogous type of construction, with no windows and no light-courts, but provided with heating and ventilating systems of the same types and of equal perform-

ances to the ones in the standard building is computed. The difference in the costs of the two completely equipped buildings is considered the investment cost of the natural lighting system.

Throughout this investigation no charges have been made against natural lighting for shades, awnings, painting, and other accessories for diffusing or eliminating direct sunlight, since their lack of standardization or of general acceptance indicates their unsatisfactoriness.

The problem of determining the cost of natural lighting may be complicated by the fact that certain things serve more than one purpose. For example, land surrounding a building and used to admit light to it, may be used for platforms, railroad sidings, yard roads, parking of automobiles, etc. In all such cases the cost of these things must be apportioned to the various purposes in accordance with the value of the service rendered.

### ANNUAL COST OF NATURAL LIGHTING.

The annual cost of natural lighting is computed in a manner analogous to the one just described. Thus the difference between the annual cost of the standard building with windows, and the annual cost of the substituted building without windows is the annual cost of natural light.

In computing annual costs, uniform rates are used for the various types and sizes of buildings. For interest, depreciation, repairs, taxes and insurance, a charge of 13 per cent. of the initial cost is made for the one-story buildings of brick and steel construction; and a charge of 10½ per cent. on multi-story buildings of reinforced-concrete construction. A charge of 13 per cent. is made for interest, depreciation, repairs, taxes, etc., on the steam-heating system. It is assumed that during the seven months of operation of the heating system, the attendance of a fireman is required for 300 hours, plus two hours for each ton of coal burned, for which he received $.65 an hour of service. It is also assumed that for seven months of the year the inside of the building is maintained at 65° F. during work-hours when there are two changes of air per hour, and at 50° F. during other times when there is no change of air. The capacity of the

heating system is such that these temperatures can be maintained with a temperature of 0° F. outdoors. Coal, delivered in the bin, is assumed to cost $5.00 a ton. It is assumed that two per cent. of the windows are broken per year and that they are replaced at $.50 per square foot, and that the washing of the windows on both sides costs 1½ cents per square foot.

### COST OF ARTIFICIAL LIGHTING.

Throughout this investigation, all buildings are assumed to have similar types of electric lighting equipment. The electric wiring is assumed to be in iron conduit and to be done in accordance with the National Electric Code. The lighting-units are assumed to be porcelain-enameled (RLM dome) steel reflectors, fitted with high-efficiency white bowl tungsten lamps mounted 11 feet six inches above the floor and spaced uniformly on 10-foot centers. The initial cost of the electric lighting equipment includes the costs of the wiring system and lighting-units complete in every particular.

The annual cost of electric lighting is assumed to consist of an overhead charge of 12 per cent. on the wiring, 21 per cent. on the lighting-units, six cleanings of the lighting-units per year at from five to ten cents per cleaning (depending upon their size), lamp renewals, and electric energy at the approximate average price of two cents per kilowatt-hour, unless otherwise stated.

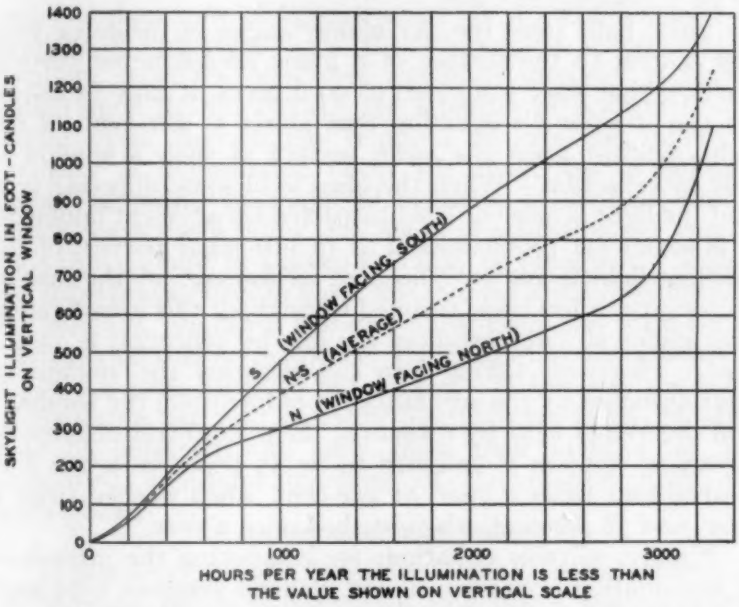
### DETERMINATION OF NATURAL ILLUMINATION.

In order to find the intensity of natural illumination at any given point upon the work-plane within the building, it is first necessary to find the brightness of, or the illumination upon, the window through which the light comes. Professor H. H. Kimball [2] has given the intensity of skylight illuminations upon plane surfaces having various orientations for any time of the year and any time of day for clear and cloudy days. Mr. M. W. Davis of the U. S. Weather Bureau in Cleveland has furnished tables showing the number of clear and cloudy days in each month of the year for Atlanta,

[2] "Daylight Illumination on Horizontal, Vertical and Sloping Surfaces," H. H. Kimball, *Trans. I. E. S.*, 18, 1923, p. 434.

Birmingham, Boston, Chicago, Cleveland, Cincinnati, New York City, Philadelphia, Pittsburgh, San Francisco, Seattle and St. Louis; and Mr. C. F. Marvin, Chief of the Weather Bureau in Washington, has furnished some data obtained in Chicago which is of use in estimating the intensity of skylight illumination on dark and rainy days.

FIG. 1.




Showing the computed number of hours per year between 7:30 A.M. and 4:30 P.M. in an average industrial center during which the intensity of skylight illumination upon an unobstructed vertical window is less than the number of foot-candles given. *N* is for windows having a northern exposure; and *S*, for windows having a southern exposure; and *N–S*, the average for northern and southern exposures.

By the use of these data the number of hours per year (between the hours of 7:30 A.M. and 4:30 P.M.) during which the intensity of illumination upon an unobstructed vertical window is less than a certain value has been computed for an average of the industrial centers mentioned above. Curves of these results for windows having northern and southern exposures are plotted in Fig. 1.

The intensity of illumination upon a vertical window may be reduced by the presence of obstacles outdoors. When the

obstacle is a parallel building of relatively great length at a distance of $W$ feet and its skyline is $H$ feet above the center of the window, it may be shown that when the sky is of uniform brightness the intensity of illumination due to it upon the window is reduced to

$$1 - H/\sqrt{H^2 + W^2} \quad \text{or} \quad 1 - \cos(\tan^{-1} W/H)$$

of its unobstructed value.

Since light from the sky makes angles of incidence with the normal to the surface of a plane unobstructed vertical window that vary from zero to 90 degrees, it may be shown by use of Fresnel's equation that about 32 per cent. of the light incident upon the outer surface of such a window is lost by reflection. When the glass is of some diffusing type and the light is more or less obstructed by adjacent buildings, it is somewhat problematical as to just what portion of the incident light is lost by reflection. However, for the sake of uniformity, it has been assumed throughout this investigation that under all circumstances the loss by reflection is 32 per cent. Therefore, taking into consideration the amount of light absorbed by the accumulation of dirt upon the window [3] and the loss of light by reflection, the overall transmission of a vertical window is assumed to be 55 per cent. when it is washed four times a year, 51 per cent. when washed twice a year, and 38 per cent. when washed once a year.

Finally, suitable equations for computing the intensities of illumination from vertical and inclined windows were used for determining the intensities of natural illumination at various points upon the work-plane.[4, 5]

By the use of these data, the intensities of natural illumination upon a work-plane three feet above the floor were computed for points underneath the various lighting-units at various distances from the windows for various intensities of illumination upon the outer surface of the window.

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[3] "Making Your Windows Deliver Daylight," W. C. Randall and A. J. Martin, *Trans. I. E. S.*, 22, 1927, p. 239.

[4] "Prediction of Daylight from Vertical Windows," H. H. Higbie, *Trans. I. E. S.*, 20, 1925, p. 433.

[5] "Prediction of Daylight from Sloping Windows," H. H. Higbie and A. Levin, *Trans. I. E. S.*, 21, 1926, p. 273.

### HOURS LIGHTING-UNITS OPERATE A YEAR.

The size of artificial lighting-unit employed in any given installation is such that it gives the "prescribed minimum" intensity of illumination upon the work-plane. The lighting-units are placed in rows parallel with the windows and each row is lighted only when the intensity of natural illumination under that row has fallen to the prescribed minimum.

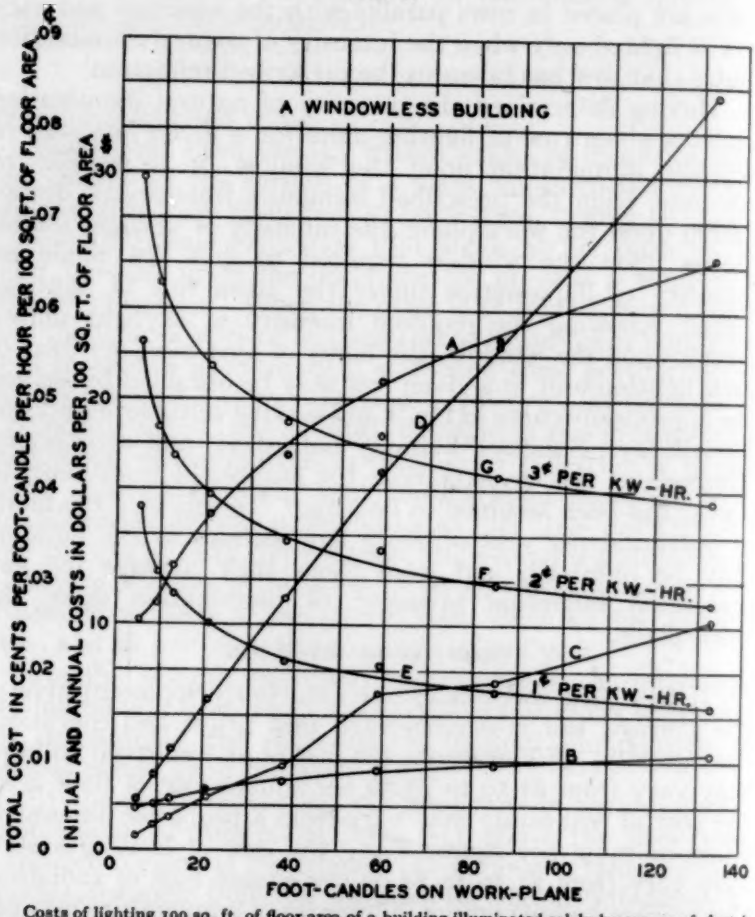
Having determined the intensity of natural illumination under a given row of lighting-units for a given intensity of skylight illumination upon the window, it is possible to compute, from the prescribed minimum intensity of illumination upon the work-plane, the intensity of skylight illumination upon the window required to give the minimum intensity of illumination under the given row of lighting-units. Knowing the required intensity of skylight illumination upon the window, the hours of operation per year of each lighting-unit in a given row may be obtained by scaling the appropriate curve in Fig. 1 and making suitable deductions for holidays, Sundays, half-day Saturdays, and noon-hours. Throughout this investigation, the number of work-hours in a year has been assumed to be 2,240. In this way the hours of operation per year of every lighting-unit in the building may be obtained, and from them their average for any prescribed minimum intensity of illumination upon the work-plane.

### CHARACTER OF DATA USED.

It has been the aim to use data fairly representative of the average, but it is recognized that prices and conditions vary greatly. For example, the cost of an industrial building may vary from $1.50 to $3.50 per square foot of floor area; the cost of real estate may vary from a negligible amount to $3.00 or more per square foot; the cost of heating system may vary from $1.50 to $2.00 per square foot of radiation; the average and maximum differences of temperature between indoors and outdoors may vary greatly with the section of country; due to obstructions, the intensity of skylight illumination upon a window may vary from zero to 100 per cent. of its unobstructed value; the average sky-brightness varies with weather conditions and the sections of country; the average transmission of a window may vary with the

type of glass used, the exposure, and frequency of washing from 5 per cent. up. Also, in certain instances costs may have to be pro-rated and thus be subject to differences of

FIG. 2.




Costs of lighting 100 sq. ft. of floor area of a building illuminated solely by means of electric lighting-units spaced uniformly on 10-foot centers. *A* shows total investment in wiring and lighting-units, complete per lighting-unit or per 100 sq. ft. of floor area; *B*, the annual overhead cost of lighting equipment; *C*, the cost of lamp renewals; *D*, the cost of electric energy at one cent per kw.-hr.; *E*, *F*, *G*, the total cost per foot-candle per hour per 100 sq. ft. of floor area for energy at respectively one, two and three cents per kw.-hr.

opinion. Therefore, in order that the reader may be able to make such recomputations, or allowances, for other conditions, costs have been itemized insofar as space permitted.

All unit costs employed throughout this investigation have been obtained from responsible building contractors, heating engineers, realtors, and others, many of whom enjoy a national reputation.

### COST OF LIGHTING VARIOUS TYPES OF INDUSTRIAL BUILDINGS.

Six types of industrial buildings have been studied. Four are single-story, and are designated as Buildings *A*, *B*, *C* and *D*; and two are multi-story, and are designated as Buildings *E* and *F*.

*Building A.*—A single-story structure of brick and steel, 60 ft. by 180 ft., with 10 ft. 3 in. continuous side windows, and flat roof, as shown in Fig. 3.

The costs of natural light and the costs of artificial light needed to supplement the natural light in maintaining a minimum of 13 foot-candles upon a horizontal work-plane three feet above the floor are presented in the table below. The space between buildings is 20 feet, the windows are washed semi-annually and the work-hours are from 7:30 A.M. to 11:30 A.M. and from 12:30 P.M. to 4:30 P.M.

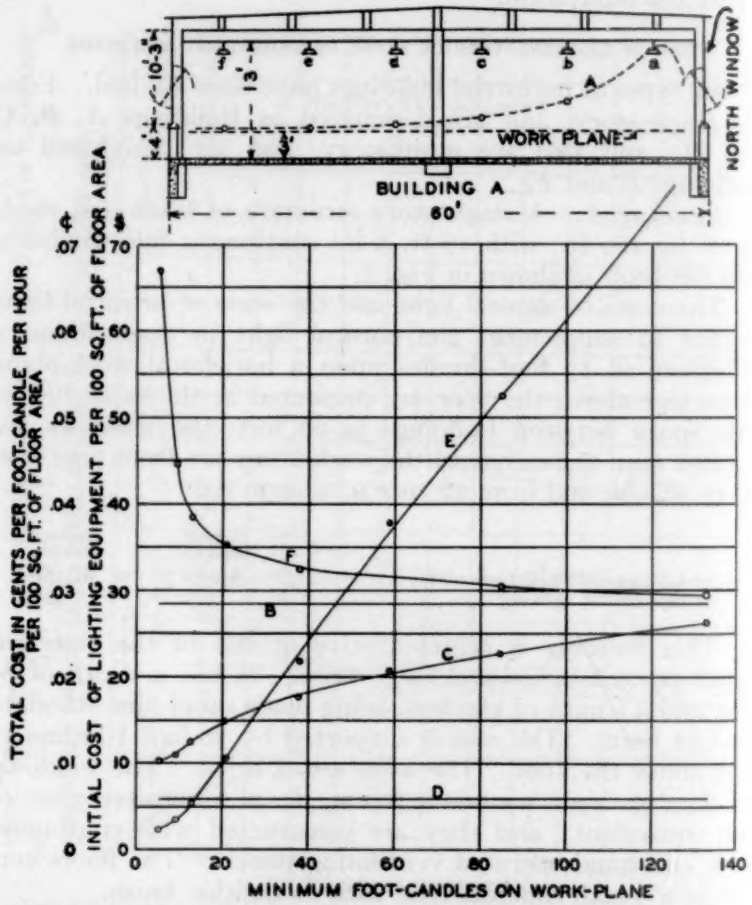
| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $3,088 | $1,371 |
| Annual cost of lighting | 630 | 578 |

This building is representative of one of the standard types erected by several large firms. It has a width of 60 feet and a length of 180 feet, being made up of nine standard 20-foot units. The roof is supported by 30-foot I-beams 13 feet above the floor. The walls are of brick. The windows, 10 ft. 3 in. high, contain 4,700 sq. ft. of hammered glass or the equivalent; and they are constructed with continuous sash and hand-operated ventilating panels. The floors consist of a 5-inch concrete base with monolithic finish.

Through the coöperation of various building contractors and engineers, the cost of this building complete with heating, ventilation, plumbing, and electric lighting was estimated to be $21,600 or $200 per 100 sq. ft. of floor area. The estimated cost of an equally satisfactory building without windows but containing hand-operated ventilating panels, etc., was estimated to be the same as the standard structure, Building *A*.

A ventilating-court, two feet wide, was assumed to surround the windowless building.

FIG. 3.




Cross-section of Building *A* and costs of natural and artificial lighting per 100 sq. ft. of floor area. The building is surrounded by a light-court 20 feet wide, costing $.40 a sq. ft. The windows are washed twice a year at a cost of 1½ cents per sq. ft. per washing, and electric energy costs two cents per kw.-hr. *A* shows the foot-candles under each lighting-unit per 100 foot-candles of illumination upon the unobstructed windows to the right; *B*, initial cost of natural lighting equipment; *C*, initial cost of electric lighting equipment; *D*, annual cost of natural lighting; *E*, annual cost of electric lighting; and *F*, the cost per minimum foot-candle per hour per 100 sq. ft. of floor area.

In Building *A* it was estimated from data supplied and used by heating engineers that 880 sq. ft. of steam radiation

was necessary to supply the heat losses incident to the windows. If the cost of the steam-heating system complete per square foot of radiation is $1.70, it follows that the initial cost of the heating equipment chargeable to natural lighting is $1,496 or $13.85 per 100 sq. ft. of floor area.

It is assumed that areas 20 ft. wide on the two sides and rear of the building are necessary for light-courts and that after making suitable deductions for the other uses made of these areas, one-half of their remaining cost is chargeable equally against the adjoining buildings. A windowless building would require a space about 2 feet wide as an air-shaft for ventilation. With a pro-rated cost of real estate of $.40 per sq. ft., which is probably a fair average price when all things are considered, the initial cost of real estate chargeable against the natural system of lighting would be $1,592 or $14.71 per 100 sq. ft. of floor area.

Thus the investment charges against the natural system of lighting per 100 sq. ft. of floor area are $0.00 for the windows and structure, $13.85 for the heating system, and $14.71 for light-courts or a total of $28.56.

With the assumptions made, the items of annual cost of natural lighting of Building *A* are:

| | |
|---|---|
| Interest, depreciation, repairs, taxes, etc., on windows and structure, $0.00 × 13% | $ 0.00 |
| Window renewals, 4,700 sq. ft. × $0.50 per sq. ft. × 2% | 47.00 |
| Washing windows, 4,700 sq. ft. × 2 × $0.015 per sq. ft. | 141.00 |
| Interest, depreciation, repairs, taxes, etc., on heating system—$1,496 × 13% | 194.48 |
| Fuel to supply window losses, 21.7 tons at $5.00 per ton | 108.50 |
| Boiler attendance, 43 hours × $.65 per hour | 27.95 |
| Interest and taxes on light-court, $1,592 × 7% | 111.44 |
| Total | $630.37 |

Therefore, the annual cost of natural lighting for Building *A* is $630 for the items considered, or is $5.83 per 100 sq. ft. of floor area. This itemized statement makes it possible for anyone to alter various items according to his own judgment and experience or for a special case. For example, the charge for light-courts is subject to wide variations due to the price of real estate and possibly to other uses being made of the courts.

It being assumed that the building is surrounded on its sides and rear by other similar buildings, distant 20 feet,

the intensity of skylight illumination upon its windows is only about 64 per cent. as much as if there were no buildings nearby. Also, since about 32 per cent. of the skylight upon the windows is lost by reflection and does not enter the building, and about 25 per cent. of the remainder is lost by absorption when the windows are washed only twice a year, it follows that only about 51 per cent. of the light falling upon the windows is transmitted to the interior.[6, 7] Thus the apparent diffuse brightness of the window as viewed from the interior is $b = .51 \times 100/3.14$ candles per square foot per 100 foot-candles of illumination upon the outside of the window due to light from the sky. By using this value of window brightness $b$ in the equation derived by Higbie,[4] the intensity of natural illumination at locations under each lighting-unit of the artificial lighting system may be computed. This value is increased by ten per cent. in the case of natural lighting to allow for reflected light from walls, ceilings, etc. In this way the intensity of natural illumination at stations under each artificial lighting-unit per 100 foot-candles of illumination upon the exterior of a window due to light from the sky was computed and is as shown plotted in curve *A*, Fig. 3. With this intensity of natural illumination under each lighting-unit per 100 foot-candles of sky illumination upon the exterior of each window, and with the curves of the number of hours per year below which the intensity of illumination upon unobstructed northern and southern windows have the values shown respectively on curves *N* and *S* in Fig. 1, the number of hours the lighting-units in each row operate per year has been computed. Thus for a minimum intensity of illumination of 13 foot-candles upon the work-plane, the number of work-hours per year each lighting-unit in each row (Fig. 3) operates is:

| | | |
|---|---|---|
| Row | *a* | 245 hours |
| " | *b* | 660 " |
| " | *c* | 1,310 " |
| " | *d* | 960 " |
| " | *e* | 500 " |
| " | *f* | 230 " |
| | Average | 651 " |

[6] "Transmission of Light through Window Glass," E. H. Hobbie and W. F. Little, *Trans. I. E. S.*, 22, 1927, p. 258.

[7] "Light and Work," M. Luckiesh, D. Van Nostrand Company, 1924.

TABLE I.

*Data upon the Cost of Lighting Various Types of Industrial Buildings Operating under Approximately Normal Conditions.*

The windows are washed twice a year; the minimum intensity of illumination upon the work-plane is 13 foot-candles; and other conditions are as stated.

| Building | *A* | *B* | *C* | *D* | *E* | *F* | *O* |
|---|---|---|---|---|---|---|---|
| Type | Flat Roof. | 6 ft. Monitor. | 34 ft.-V-type Monitor. | Sawtooth. | Multi-story. | Multi-story. | Flat Roof Windowless. |
| Ground dimensions in feet | 60 × 180 | 60 × 180 | 100 × 200 | 120 × 180 | 60 × 180 | 60 × 180 | 60 × 180 |
| No. of stories | 1 | 1 | 1 | 1 | 6 | 5 | 1 |
| Type of construction | Brick and steel | Brick and steel | Brick and steel | Brick and steel | Rein. con. | Rein. con. | Brick and steel |
| Space between buildings in feet | 20 | 20 | 20 | 20 | 80 | 80 | 2 |
| Square ft. of floor area | 10,800 | 10,800 | 20,000 | 21,600 | 64,800 | 54,000 | 10,800 |
| Square ft. of window area | 4,700 | 6,560 | 10,935 | 10,860 | 20,800 | 27,750 | 0 |
| Ratio of window area to floor area | .435 | .607 | .546 | .503 | .321 | .514 | 0 |
| Proportion of sky illuminating side windows | .64 | .64 | .64 | .55 | .31 to .89 | .30 to .90 | — |
| Proportion of sky illuminating monitor windows | — | .95 | .95 | 1.00 | — | — | — |
| Cost of building complete | $21,600 | $22,680 | $41,000 | $49,680 | $194,400 | $183,600 | $21,600 |
| *Investment cost of natural lighting equipment:* | | | | | | | |
| Windows and structure | $ 0 | $1,080 | $4,000 | $9,720 | $ 0 | $21,600 | $0 |
| Heating system to supply window losses | 1,496 | 2,660 | 6,410 | 5,740 | 6,630 | 12,400 | 0 |
| Real estate at $.40 per sq. ft. chargeable to light-courts | 1,592 | 1,592 | 1,880 | 1,810 | 7,840 | 7,840 | 0 |

TABLE I (*Continued*).

*Investment costs for natural lighting per 100 sq. ft. of floor area:*

| Building | *A* | *B* | *C* | *D* | *E* | *F* | *O* |
|---|---|---|---|---|---|---|---|
| Type | Flat Roof. | 6 ft. Monitor. | 34 ft.-V-type Monitor. | Sawtooth. | Multi-story. | Multi-story. | Flat Roof Windowless. |
| Windows and structure | $ 0.00 | $10.00 | $20.00 | $45.00 | $ 0.00 | $40.00 | $0.00 |
| Heating system | 13.85 | 24.60 | 32.10 | 26.50 | 10.30 | 22.95 | 0.00 |
| Real estate at $.40 per sq. ft. | 14.71 | 14.71 | 9.40 | 8.40 | 12.09 | 14.50 | 0.00 |
| TOTAL | $28.56 | $49.31 | $61.50 | $79.90 | $22.39 | $77.45 | $0.00 |
| *Annual cost of natural lighting per 100 sq. ft. of floor area:* | | | | | | | |
| Int., dep., rep., taxes, etc., on windows and structure | $0.44 | $ 1.91 | $ 3.15 | $ 6.35 | $ .32 | $ 4.71 | $0.00 |
| Heat losses through windows | 3.06 | 5.42 | 6.71 | 5.69 | 2.28 | 4.85 | 0.00 |
| Real estate—7% | 1.03 | 1.03 | .66 | .58 | .85 | 1.02 | 0.00 |
| Washing windows twice | 1.30 | 1.82 | 1.64 | 1.5. | .96 | 1.54 | 0.00 |
| TOTAL | $5.83 | $10.18 | $12.16 | $14.13 | $4.41 | $12.12 | $0.00 |
| *Investment cost of electric lighting system per 100 sq. ft. of floor area for 13 f.c.:* | | | | | | | |
| Electric wiring,—complete | $ 8.65 | $ 8.65 | $ 8.65 | $ 8.65 | $ 8.65 | $ 8.65 | $ 8.65 |
| Lighting-units, installed | 4.05 | 4.05 | 4.05 | 4.05 | 4.05 | 4.05 | 4.05 |
| TOTAL | $12.70 | $12.70 | $12.70 | $12.70 | $12.70 | $12.70 | $12.70 |

TABLE I (*Continued*).

TABLE I (*Continued*).

*Annual cost of electric lighting per 100 sq. ft. of floor area for a minimum of 13 f.c.:*

| Building | *A* | *B* | *C* | *D* | *E* | *F* | *O* |
|---|---|---|---|---|---|---|---|
| Type | Flat Roof. | 6 ft. Monitor. | 34 ft.-V-type Monitor. | Sawtooth. | Multi-story. | Multi-story. | Flat Roof Windowless. |
| Int., dep., rep., etc., on electric equip.—12% | $1.04 | $1.04 | $1.04 | $1.04 | $1.04 | $1.04 | $1.04 |
| Int., dep., rep., etc., on lighting-units—21% | .85 | .85 | .85 | .85 | .85 | .85 | .85 |
| Cleaning lighting-units six times a year | .42 | .42 | .42 | .42 | .42 | .42 | .42 |
| TOTAL OVERHEAD COST | $2.31 | $2.31 | $2.31 | $2.31 | $2.31 | $2.31 | $2.31 |
| Annual no. of hours of operation per lighting-unit | 651 | 379 | 256 | 253 | 1187 | 704 | 2240 |
| Lamp renewals | $0.44 | $ .25 | $ .17 | $ .17 | $ .80 | $ .47 | $ 1.50 |
| Electric energy at 2¢ per kw.-hr. | 2.60 | 1.52 | 1.02 | 1.01 | 4.75 | 2.81 | 8.96 |
| TOTAL COST OF ELECTRIC LIGHTING | $5.35 | $4.08 | $3.50 | $3.49 | $7.86 | $5.59 | $12.77 |
| *Total annual cost of lighting per 100 sq. ft. of floor area for a minimum of 13 f.c.:* | | | | | | | |
| Natural lighting | $ 5.83 | $10.18 | $12.16 | $14.13 | $ 4.41 | $12.12 | $ 0.00 |
| Electric lighting | 5.35 | 4.08 | 3.50 | 3.49 | 7.86 | 5.59 | 12.77 |
| TOTAL FOR NATURAL AND ELECTRIC LIGHTING | $11.18 | $14.26 | $15.66 | $17.62 | $12.27 | $17.71 | $12.77 |
| Cost per min. foot-candle per hour per 100 sq. ft. of floor area | .0384¢ | .0489¢ | .0537¢ | .0605¢ | .0421¢ | .0608¢ | .0438¢ |

Thus when natural lighting in Building *A* is supplemented by artificial lighting during the assumed work-hours, the lighting-units operate on an average of 651 hours per year out of a total of 2,240 in maintaining a minimum of 13 foot-candles upon the work-plane.

The artificial lighting equipment is designed to give a uniform intensity of illumination of 13 foot-candles upon a horizontal work-plane three feet above the floor and consists of 108 porcelain enameled (RLM dome) steel reflectors, each fitted with a 200-watt white bowl high-efficiency tungsten lamp. The cost of the wiring complete at $8.65 per outlet is $934; and the cost of lighting-units installed at $4.05 each is $437. Thus the total investment cost for artificial lighting is $1,371, or a total cost of $12.70 per 100 sq. ft. of floor area.

With the assumptions made, the items of annual cost of artificial lighting used to supplement natural lighting in maintaining the prescribed minimum of 13 foot-candles upon the work-plane are:

| | |
|---|---|
| Interest, depreciation, repairs, taxes, etc., on wiring, $934 × 12%..... | $112.00 |
| Interest, depreciation, repairs, taxes, etc., on lighting-units, $437 × 21% | 91.80 |
| Cleaning lighting-units six times, 108 × 6 × $.07..... | 45.36 |
| Lamp renewals, 108 × 651 × $.67/1000..... | 47.10 |
| Electric energy at two cents per kw.-hr., 108 × 651 × 200/1000 × $.02. | 281.24 |
| Total..... | $577.50 |

Therefore, the total annual cost of artificial lighting is $577.50 or an annual cost of $5.35 per 100 sq. ft. of floor area.

A summary of all these costs is presented at the beginning of this section and in the second column of Table I.

*Building B.*—A single-story structure of brick and steel, 60 ft. by 180 ft., with 4,700 sq. ft. of 10 ft. 3 in. continuous side windows and 1,860 sq. ft. of 5 ft. 2 in. windows in a monitor 6 ft. wide.

The costs of natural light and the costs of artificial light needed to supplement the natural light in maintaining a minimum of 13 foot-candles upon a horizontal work-plane three feet above the floor are presented in the table below. The space between buildings is 20 feet, the windows are washed semi-annually and the work-hours are from 7:30 A.M. to 11:30 A.M. and from 12:30 P.M. to 4:30 P.M.:

| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $5,332 | $1,371 |
| Annual cost of lighting | 1,100 | 440 |

This building is similar in design and construction to Building *A* excepting that it has a monitor 6 feet wide down the center of its roof. The cost of this monitor is about $1,080 and is entirely chargeable to natural lighting. The heating system requires about 1,565 sq. ft. of radiation to supply heat losses due to the windows. Assuming the installation cost of the heating system per sq. ft. of radiation to be $1.70, the initial cost of the heating system chargeable to natural lighting is thus 1,565 × $1.70, or $2,660. With an intervening space between buildings of 20-foot width, the cost of real estate at $.40 per sq. ft. chargeable against natural lighting is $1,592. Therefore, the initial cost of the natural lighting equipment is $1,080 for windows and structure, $2,660 for heating system, and $1,592 for light-courts, or a total of $5,332, as stated above.

With light-courts of 20-foot width, the intensity of skylight illumination upon the windows is only about 64 per cent. of its unobstructed value upon the side windows, and 95 per cent. of it upon the monitor windows. Therefore, with the windows washed twice a year, and with a minimum intensity of illumination upon the work-plane of 13 foot-candles, the average time of operation of a lighting-unit is 379 hours per year.

Following the method of computation previously outlined, the costs of lighting are as given at the head of this section and as presented in the third column of Table I.

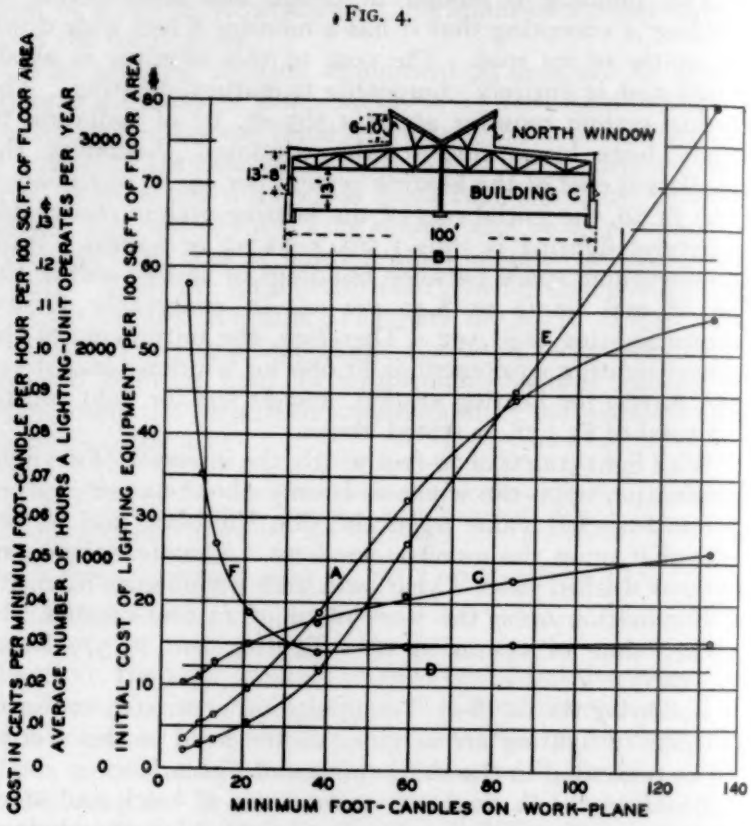
*Building C.*—A single-story structure of brick and steel, 100 ft. by 200 ft., with 8,200 sq. ft. of 13 ft. 8 in. side windows and 2,735 sq. ft. of 6 ft. 10 in. vertical windows in a V-type monitor, as shown in Fig. 4.

With 20 feet between adjacent buildings, the windows washed twice a year, and a minimum of 13 foot-candles upon the work-plane, the costs of lighting are:

| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $12,290 | $2,540 |
| Annual cost of lighting | 2,432 | 700 |

In this building the cost of windows and structure chargeable to natural lighting is about $4,000. The radiation required to supply losses due to windows is 3,770 sq. ft.

FIG. 4.



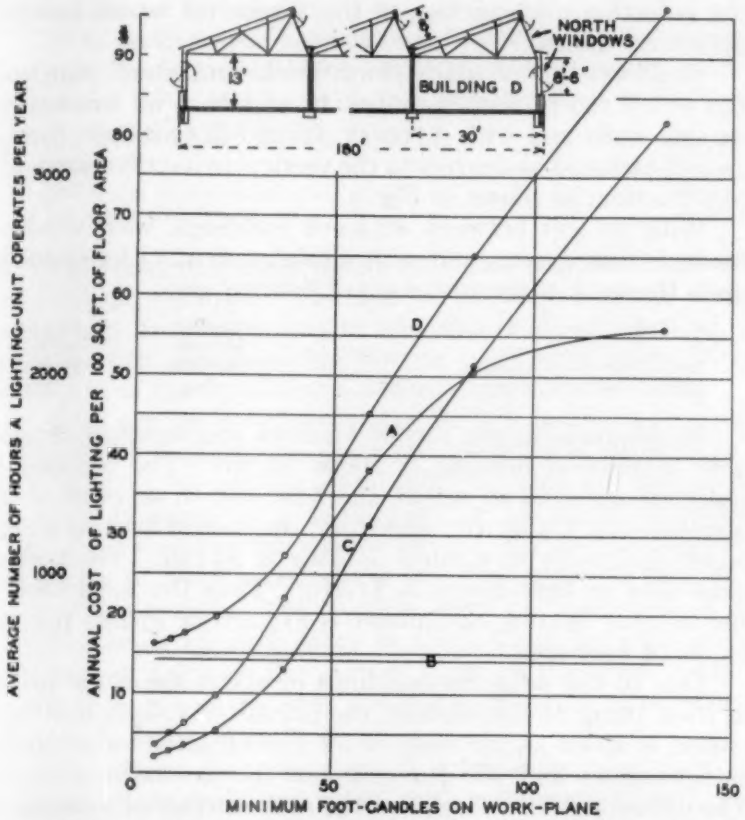

Costs of lighting Building *C* when it is surrounded by a light-court 20 feet wide costing $.40 a sq. ft. and when windows are washed twice a year. *A* shows the average number of hours per year lighting-units operate; *B*, the initial cost of equipment for natural lighting per 100 sq. ft. of floor area; *C*, the initial cost of the electric lighting equipment; *D*, the annual cost of natural lighting; *E*, the annual cost of electric lighting; *F*, the total cost of lighting per minimum foot-candle per hour per 100 sq. ft. of floor area.

and the initial cost of heating system chargeable to natural lighting is 3,770 × $1.70 or $6,410. The cost of real estate in light-courts at $.40 per sq. ft. is $1,880.

With the light-courts of 20-foot width the intensity of skylight illumination is about 64 per cent. of its unobstructed

value upon the side windows and 95 per cent. of it upon the monitor windows. With the undersurface of the V-monitor having a reflection-factor of 63 per cent., and with the windows washed twice a year, the average time of operation

FIG. 5.




Lighting-cost data for sawtooth Building *D*, when surrounded by a light-court 20 ft. wide, costing $.40 per sq. ft. The windows are washed twice a year, and electric energy costs two cents per kw.-hr. *A* shows the average number of hours of operation per year per lighting-unit; *B*, the annual cost of natural lighting per 100 sq. ft. of floor space; *C*, the annual cost of electric lighting; and *D*, the annual cost of natural and electric lighting.

of a lighting-unit for a minimum of 13 foot-candles upon the work-plane is 256 hours per year. With these data the costs of natural and electric lighting are as given at the head of this section and as tabulated in the fourth column of Table I.

It may be noted here that with this building surrounded by other buildings of about its own height and distant from it 20 feet or more, and with its windows of a diffusing type of glass, the intensity of illumination upon its work-plane is fairly high and uniform; but if it were surrounded by high buildings and if its windows were of a clear plane type of glass, the reflecting undersurface of the V-monitor would be comparatively useless.

*Building D.*—A single-story brick and steel structure, 120 ft. by 180 ft. with 5,100 sq. ft. of 8 ft. 6 in. windows in its side walls and with 5,760 sq. ft. of 8-ft. windows having an inclination of 30 degrees to the vertical in a roof of sawtooth construction, as shown in Fig. 5.

With 20 feet between adjacent buildings, with windows washed twice a year, and with a minimum of 13 foot-candles upon the work-plane, the costs of lighting are:

| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $17,270 | $2,743 |
| Annual cost of lighting | 3,042 | 754 |

In this building the cost of windows and structure chargeable to natural lighting is about $9,720. The amount of radiation required to supply the heat lost on account of the windows is 3,375 sq. ft.; therefore, the cost of heating equipment chargeable to natural lighting is $5,740. The cost of land used in light-courts is $1,810. Thus the total cost of the natural lighting equipment is $17,270 or $79.90 per 100 sq. ft. of floor area.

Due to the adjacent buildings of about the same height as itself being 20 feet distant, the intensity of skylight illumination is about 55 per cent. of its unobstructed value on the side windows and 100 per cent. on the sawtooth windows. The diffuse reflection-factor of the undersurface of a sawtooth is assumed to be 63 per cent. With the windows washed twice a year, the total transmission of the side windows was assumed to be 51 per cent., and the transmission of the inclined sawtooth windows, 49 per cent. When it is assumed that the sawtooth windows face the north, the computed average time of operation of a lighting-unit is 253 hours per year for a minimum intensity of illumination upon the work-plane of 13 foot-candles.

Using these data, the costs of lighting the building are as given at the head of this section and in the fifth column of Table I.

*Building E.*—A six-story reinforced concrete structure, 60 ft. by 180 ft., with pitch of ceiling in each story 13 feet high and the windows uniformly 8 ft. 6 in. high, containing 20,800 square feet of glass.

With 80-foot spacings between buildings, with real estate costing $.40 a square foot, with windows washed twice a year, and for a minimum of 13 foot-candles upon the work-plane, the costs of lighting are:

| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $14,470 | $8,230 |
| Annual cost of lighting | 2,858 | 5,093 |

This structure costs about the same whether made with or without windows. The amount of steam radiator surface to supply heat losses due to windows is about 3,900 sq. ft., which, with accompanying heating equipment, costs $6,630. The cost of the light-courts at $.40 per sq. ft. is $7,840.

With similar buildings spaced 80 feet apart, the intensity of skylight illumination upon the windows of each story in per cent. of its unobstructed value is from the first to the sixth story respectively as follows: 31, 38, 48, 59, 73 and 89. When the windows are washed twice a year and the minimum intensity of illumination upon the work-plane of each story is 13 foot-candles, the average time of operation of the lighting-units on each story is 1,615 hours per year on the first story, 1,470 on the second, 1,300 on the third, 1,105 on the fourth, 915 on the fifth, and 715 on the sixth, or an average for the building of 1,187 hours per year.

With these data, the costs of lighting are as given at the head of this section and in the sixth column of Table I.

*Building F.*—A five-story reinforced concrete structure, 60 ft. by 180 ft., with the height of windows on each floor such that the amount of natural lighting in each story is substantially the same when the light-courts are 80 feet wide. The height of windows in each story from first to fifth is 20, 16, 13, 10½, and 8½ feet respectively; and the total window surface, allowing for 3-foot mullions, is 27,750 sq. ft.

With 80 feet between adjacent buildings, the windows washed twice a year, and a minimum of 13 foot-candles upon the work-plane of each story, the costs of lighting are:

| | Natural Lighting. | Artificial Lighting. |
|---|---|---|
| Initial cost of installation | $41,840 | $6,858 |
| Annual cost of lighting | 6,545 | 3,019 |

The cost of the windows and structure chargeable to natural lighting is $21,600. The amount of steam radiation required to supply the heat loss due to the windows is about 7,290 sq. ft., giving a cost of heating equipment chargeable to natural lighting of $12,400. The cost of the 80-foot light-court at $.40 per sq. ft. chargeable against natural lighting is $7,840. Thus the total cost of natural lighting equipment is $41,840 or a total cost of $77.45 per 100 sq. ft. of floor area.

With the 80-foot light-court between buildings the intensity of skylight illumination upon the windows of each story in per cent. of its unobstructed value is for each story from the first to the fifth respectively as follows: 30, 42, 57, 73 and 90. When the windows are washed twice a year and the minimum intensity of illumination upon the work-plane of each story is 13 foot-candles, the average time of operation of a lighting-unit on each story is within about plus or minus five per cent. of 704 hours per year.

With these data the costs of lighting are as given at the head of this section and in the seventh column of Table I.

It does not appear that this type of building is justifiable from the standpoint of economy in lighting.

#### COST OF LIGHTING SOLELY BY ARTIFICIAL MEANS.

Since it would be interesting to know not only the investment costs but the total annual cost of lighting a building solely by artificial means, these costs have been worked out for various intensities of illumination ranging from 5.5 to 133 foot-candles upon a work-plane 3 feet above the floor. It is assumed that the general dimensions of the building, the wall and ceiling finishes, height of ceiling, the type and cost of electric wiring, type and cost of electric lighting-units, mounting height, and spacings are the same as in all the standard types of buildings investigated for the same

TABLE II.

*Showing Details of Cost of Lighting a Windowless One-Story Industrial Building to Various Levels of Illumination.*

The building has a ceiling height of thirteen feet, a fairly light ceiling and dark walls. The lighting-units are porcelain enameled (RLM dome) steel reflectors fitted with white bowl high-efficiency tungsten lamps, mounted 11½ feet from the floor and spaced uniformly on 10-foot centers. The lighting-units are assumed to be cleaned six times a year and the lamps are in an average condition. The number of work-hours per year is assumed to be 2240.

| Foot-candles<br>Watts per Lamp | 5.5<br>100 | 9.4<br>150 | 13<br>200 | 21<br>300 | 38<br>500 | 59<br>750 | 85<br>1,000 | 133<br>1,500 |
|---|---|---|---|---|---|---|---|---|
| *Installation costs per lighting-unit or per 100 sq. ft. of floor area:* | | | | | | | | |
| Electric wiring—complete | $ 6.85 | $ 7.48 | $ 8.65 | $ 9.93 | $12.50 | $14.41 | $16.24 | $19.72 |
| Lighting-unit—installed | 3.35 | 3.52 | 4.05 | 4.97 | 5.00 | 6.39 | 6.46 | 6.58 |
| TOTAL PER OUTLET | $10.20 | $11.00 | $12.70 | $14.90 | $17.50 | $20.80 | $22.70 | $26.30 |
| *Annual cost per lighting-unit or per 100 sq. ft. of floor area:* | | | | | | | | |
| Int., dep., etc., on electric wiring—12% | $ 0.82 | $ .90 | $ 1.04 | $ 1.19 | $ 1.50 | $ 1.73 | $ 1.95 | $ 2.37 |
| Int., dep., etc., on lighting-unit—21% | .70 | .74 | .85 | 1.04 | 1.05 | 1.34 | 1.36 | 1.38 |
| Cleaning six times | .30 | .36 | .42 | .48 | .48 | .54 | .54 | .60 |
| Cost of lamp renewals | .63 | 1.14 | 1.50 | 2.40 | 3.81 | 6.99 | 7.53 | 10.26 |
| Cost of electric energy at 2¢ per kw.-hr. | 4.48 | 6.72 | 8.96 | 13.44 | 22.40 | 33.60 | 44.80 | 67.20 |
| TOTAL ANNUAL OPERATING COSTS PER LIGHTING UNIT | $ 6.93 | $ 9.86 | $12.77 | $18.55 | $29.24 | $44.20 | $56.18 | $81.81 |
| Cost per f.c. per hour per 100 sq. ft. of floor area | .0563¢ | .0468¢ | .0438¢ | .0394¢ | .0343¢ | .0335¢ | .0295¢ | .0275¢ |

minimum intensity of illumination upon the work-plane. The total time of operation of each lighting-unit is, of course, the entire work-year. When work-hours are from 7:30 A.M. to 11:30 A.M. and 12:30 P.M. to 4:30 P.M., and when holidays, Sundays, and half-day Saturdays are deducted, there remain approximately 2,240 work-hours per year, the value used throughout this investigation.

The items of cost for each level of illumination are presented in Table II and shown graphically in Fig. 2. It may be observed that when a building is lighted solely by artificial means, the cost per foot-candle per hour per 100 sq. ft. of floor area decreases rapidly at first and later more gradually as the intensity of illumination upon the work-plane is increased.

### LIGHTING COSTS VERSUS INTENSITY OF ILLUMINATION.

In order to ascertain how the annual costs of natural and artificial lighting vary with the minimum intensity of illumination upon the work-plane, these costs have been computed for each building for various intensities of illumination. The results for the four single-story buildings for intensities of illumination ranging from 5.5 to 133 foot-candles are presented in Table III. The assumed conditions are that these buildings are surrounded by 20-foot light-courts costing $.40 per sq. ft., that the windows are washed twice a year at a cost of 1½ cents per sq. ft. per washing, and that electric energy costs two cents per kw.-hr. A plot of the results for Buildings *A*, *C*, and *D* are shown respectively in Figs. 3, 4 and 5.

The annual costs of natural and artificial lighting were computed for Building *E* for the minimum intensities of illumination of 13 and 21 foot-candles with the width of light-court surrounding the buildings varied from 2 to 150 ft., and the cost per sq. ft. of light-court at $1.50 and $.40. The windows which are uniformly 8½ feet high on all six stories are assumed to be washed twice a year. These results are presented in tabular form in Table IV, and graphically, in Fig. 6.

The annual costs of natural and artificial lighting were computed for Building *F* for the minimum intensities of

TABLE III.

*Annual Cost of Lighting per 100 Square Feet of Floor Area of Various Types of Single-Story Industrial Buildings.*

The buildings are spaced 20 feet apart; windows are washed twice a year; and one-half of the cost of the intervening space at the sides and rear of the buildings is charged to natural lighting at $.40 per square foot. The annual costs for lighting are given in dollars per 100 sq. ft. of floor area; and the costs per minimum foot-candle per hour per 100 sq. ft. are given in cents.

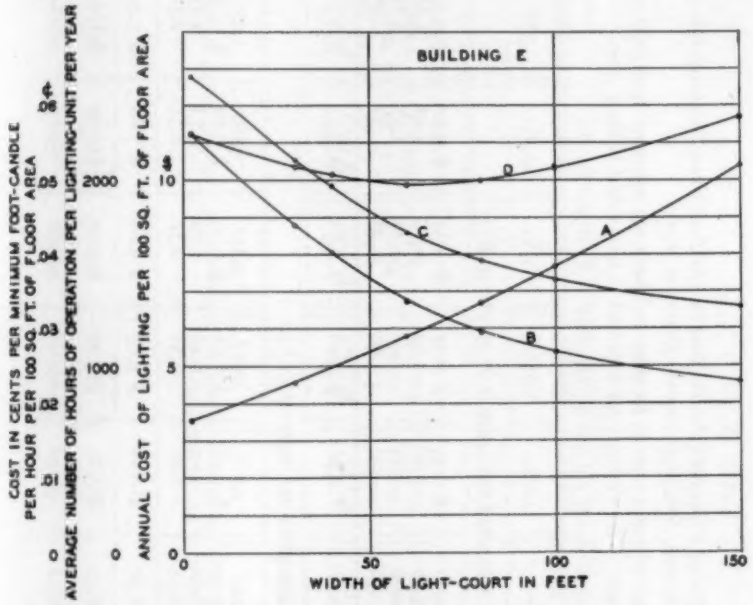
| Min. Foot-candles<br>Watts per Lamp | 5.5<br>100 | 9.4<br>150 | 13<br>200 | 21<br>300 | 38<br>500 | 59<br>750 | 85<br>1,000 | 133<br>1,500 |
|---|---|---|---|---|---|---|---|---|
| *Building A* | | | | | | | | |
| Ave. no. of hours lamps operate per yr. | 267 | 448 | 651 | 1,140 | 1,605 | 1,902 | 2,080 | 2,240 |
| Annual cost of natural lighting | $ 5.83 | $ 5.83 | $ 5.83 | $ 5.83 | $ 5.83 | $ 5.83 | $ 5.83 | $ 5.83 |
| Annual cost of electric lighting | 2.43 | 3.57 | 5.35 | 10.77 | 21.81 | 38.08 | 52.44 | 81.81 |
| Annual cost of natural and electric lighting | 8.26 | 9.40 | 11.18 | 16.60 | 27.64 | 43.91 | 58.27 | 87.64 |
| Cents per min. f.c. per hour per 100 sq. ft. of floor area | .0670¢ | .0447¢ | .0384¢ | .0353¢ | .0325¢ | .0332¢ | .0306¢ | .0294¢ |
| *Building B* | | | | | | | | |
| Ave. no. of hours lamps operate per year | 195 | 298 | 379 | 663 | 1,352 | 1,860 | 2,053 | 2,225 |
| Annual cost of natural lighting | $10.18 | $10.18 | $10.18 | $10.18 | $10.18 | $10.18 | $10.18 | $10.18 |
| Annual cost of electric lighting | 2.26 | 3.04 | 4.08 | 7.40 | 18.85 | 37.32 | 51.81 | 81.24 |
| Annual cost of natural and electric lighting | 12.44 | 13.22 | 14.26 | 17.58 | 29.03 | 47.50 | 61.99 | 91.42 |
| Cents per min. f.c. per hr. per 100 sq. ft. floor area | .1010¢ | .0628¢ | .0489¢ | .0374¢ | .0341¢ | .0359¢ | .0326¢ | .0307¢ |

TABLE III (*Continued*).

| Min. Foot-candles<br>Watts per Lamp | 5.5<br>100 | 9.4<br>150 | 13<br>200 | 21<br>300 | 38<br>500 | 59<br>750 | 85<br>1,000 | 133<br>1,500 |
|---|---|---|---|---|---|---|---|---|
| *Building C* | | | | | | | | |
| Average no. of hrs. lamps operate per yr. | 141 | 205 | 256 | 385 | 748 | 1,290 | 1,776 | 2,173 |
| Annual cost of natural lighting | $12.16 | $12.16 | $12.16 | $12.16 | $12.16 | $12.16 | $12.16 | $12.16 |
| Annual cost of electric lighting | 2.14 | 2.72 | 3.50 | 5.43 | 11.78 | 26.99 | 45.32 | 79.50 |
| Annual cost of natural and electric lighting | 14.30 | 14.88 | 15.66 | 17.59 | 23.94 | 39.15 | 57.48 | 91.66 |
| Cents per min. f.c. per hr. per 100 sq. ft. floor area | .1160¢ | .0706¢ | .0537¢ | .0374¢ | .0281¢ | .0296¢ | .0302¢ | .0307¢ |
| *Building D* | | | | | | | | |
| Average no. of hrs. lamps operate per year | 142 | 203 | 253 | 390 | 878 | 1,523 | 2,025 | 2,240 |
| Annual cost of natural lighting | $14.13 | $14.13 | $14.13 | $14.13 | $14.13 | $14.13 | $14.13 | $14.13 |
| Annual cost of electric lighting | 2.14 | 2.71 | 3.49 | 5.47 | 13.20 | 31.21 | 51.15 | 81.81 |
| Annual cost of natural and electric lighting | 16.27 | 16.84 | 17.62 | 19.60 | 27.33 | 45.34 | 65.28 | 95.94 |
| Cents per min. f.c. per hr. per 100 sq. ft. floor area | .1320¢ | .0800¢ | .0605¢ | .0417¢ | .0321¢ | .0343¢ | .0343¢ | .0322¢ |

illumination of 9.4, 13, and 21 foot-candles with the light-courts 80 feet wide and with real estate at $1.50 and $.40 per sq. ft. The results obtained are presented in Table V.

FIG. 6.


BUILDING E
COST IN CENTS PER MINIMUM FOOT-CANDLE PER HOUR PER 100 SQ. FT. OF FLOOR AREA
AVERAGE NUMBER OF HOURS OF OPERATION PER LIGHTING-UNIT PER YEAR
ANNUAL COST OF LIGHTING PER 100 SQ. FT. OF FLOOR AREA
WIDTH OF LIGHT-COURT IN FEET
A
B
C
D

Cost data on six-story Building *E* when surrounded by light-courts of various widths, costing $1.50 per sq. ft. The windows are washed twice a year and electric energy costs two cents per kw.-hr. *A* shows the annual cost of natural lighting per 100 sq. ft. of floor area; *B*, the average number of hours of operation a year of the 200-watt lighting-units in maintaining a minimum intensity of illumination of 13 foot-candles on the work-plane of each story; *C*, the annual cost of electric lighting: and *D*, the cost per minimum foot-candle per hour per 100 sq. ft. of floor area.

When the minimum intensity of illumination desired upon the work-plane is less than about 10 foot-candles or more than 75, artificial illumination is the more economical one. Between these limits, usually at about 38 foot-candles, the combined cost of natural and artificial illumination per foot-candle per hour attains a minimum. The determination of which one should be employed to supply the major portion of light would naturally depend upon the relative costs of building, real estate, and electric energy.

TABLE IV.

*Cost of Lighting Building E, a Six-story Building Having a Ground Area 60 Feet by 180 Feet, when Surrounded by Other Buildings of Similar Dimensions, Spaced at Various Distances Apart.*

The spaces intervening between the building and adjacent ones at its sides and back are assumed to be light-courts and their cost to be divided equally between adjacent buildings. The windows are assumed to be washed twice a year.

*Building E—when minimum illumination is 13 foot-candles and the cost of real estate is $1.50 per sq. ft.:*

| Width of Court between Buildings in Feet | 2 | 30 | 40 | 60 | 80 | 100 | 150 |
|---|---|---|---|---|---|---|---|
| *Annual cost of natural lighting per 100 sq. ft. of floor area when real estate is $1.50 per sq. ft.:* | | | | | | | |
| Windows and structure | $ 0.32 | $ 0.32 | $ 0.32 | $ 0.32 | $ 0.32 | $ 0.32 | $ 0.32 |
| Heating | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 |
| Real estate at $1.50 per sq. ft. | 0.00 | 1.02 | 1.42 | 2.26 | 3.17 | 4.14 | 6.86 |
| Washing windows twice | .96 | .96 | .96 | .96 | .96 | .96 | .96 |
| TOTAL | $ 3.56 | $ 4.58 | $ 4.98 | $ 5.82 | $ 6.73 | $ 7.70 | $10.42 |
| *Annual cost of electric lighting per 100 sq. ft. of floor area for min. illum. of 13 f.c.:* | | | | | | | |
| Av. no. hours lamps operate a year | 2,240 | 1,762 | 1,615 | 1,347 | 1,187 | 1,077 | 918 |
| Lamp renewals—(200-watt) | $ 1.50 | $ 1.18 | $ 1.08 | $ 0.90 | $ 0.80 | $ 0.72 | $ 0.61 |
| Elec. energy at 2¢ per kw.-hr. | 8.96 | 7.05 | 6.46 | 5.39 | 4.75 | 4.31 | 3.67 |
| Int., dep., etc., of elec. lighting system | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| TOTAL | $12.77 | $10.54 | $ 9.85 | $ 8.60 | $ 7.86 | $ 7.34 | $ 6.59 |
| Total ann. cost of nat. and elec. lighting | $16.33 | $15.12 | $14.83 | $14.42 | $14.59 | $15.04 | $17.01 |
| Total cost per min. f.c. per hr. per 100 sq. ft. floor area | .0561¢ | .0519¢ | .0509¢ | .0495¢ | .0501¢ | .0516¢ | .0584¢ |

TABLE IV (*Continued*).

| Width of Court between Buildings in Feet..... | 2 | 30 | 40 | 60 | 80 | 100 | 150 |
|---|---|---|---|---|---|---|---|
| *Building E—when min. illum. is 21 f.c. and real estate is $1.50 per sq. ft.:* | | | | | | | |
| Av. no. hrs. lamps operate a yr..... | 2,240 | 1,974 | 1,822 | 1,689 | 1,564 | 1,478 | 1,350 |
| Ann. cost of nat. lighting..... | $ 3.56 | $ 4.58 | $ 4.98 | $ 5.82 | $ 6.73 | $ 7.70 | $10.42 |
| Ann. cost of elec. lighting..... | 18.55 | 16.66 | 15.59 | 14.65 | 13.76 | 13.16 | 12.26 |
| Total ann. cost of nat. and electric lighting. | 22.11 | 21.24 | 20.57 | 20.47 | 20.49 | 20.86 | 22.68 |
| Cost per min. f.c. per hr. per 100 sq. ft. floor | .0470¢ | .0452¢ | .0437¢ | .0435¢ | .0435¢ | .0444¢ | .0482¢ |
| *Building E—when real estate is $.40 per sq. ft.:* | | | | | | | |
| Cost per min. f.c. per hr. per 100 sq. ft. of floor area when min. illum. is 13 f.c.... | .0560¢ | .0493¢ | .0473¢ | .0438¢ | .0421¢ | .0411¢ | .0411¢ |
| Cost per min. f.c. per hr. per 100 sq. ft. of floor area when min. illum. is 21 f.c.... | .0470¢ | .0436¢ | .0415¢ | .0400¢ | .0386¢ | .0378¢ | .0375¢ |

TABLE V.

*Cost of Lighting Building F,—a Five-story Building with Window Heights of 20, 16, 13, 10½ and 8½ Feet or with Window Heights Such as to Necessitate about Equal Amounts of Electric Lighting to Supplement the Natural Lighting in Order to Maintain the Same Minimum Intensity of Illumination upon the Work-plane of Each Story.*

The building is assumed to be spaced 80 ft. from adjacent ones and to be charged with one-half of the cost of the light-courts at its sides and rear.

| | Costs with Real Estate at $1.50 per Sq. Ft. | | | Costs with Real Estate at $.40 per Sq. Ft. | | |
|---|---|---|---|---|---|---|
| Min. foot-candles | 9.4 | 13 | 21 | 9.4 | 13 | 21 |
| Watts per lamp | 150 | 200 | 300 | 150 | 200 | 300 |
| Av. no. of hours lamps operate a year | 455 | 704 | 1,219 | 455 | 704 | 1,219 |
| *Annual cost of natural lighting per 100 sq. ft. of floor area:* | | | | | | |
| Windows and structure | $ 4.71 | $ 4.71 | $ 4.71 | $ 4.71 | $ 4.71 | $ 4.71 |
| Real estate | 3.81 | 3.81 | 3.81 | 1.02 | 1.02 | 1.02 |
| Heating | 4.85 | 4.85 | 4.85 | 4.85 | 4.85 | 4.85 |
| Washing windows | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 |
| Total cost of natural lighting | $14.91 | $14.91 | $14.91 | $12.12 | $12.12 | $12.12 |
| *Annual cost of electric lighting per 100 sq. ft. of floor area:* | | | | | | |
| Overhead cost of electric lighting equipment | $ 2.00 | $ 2.31 | $ 2.71 | $ 2.00 | $ 2.31 | $ 2.71 |
| Lamp renewals | .23 | .47 | 1.30 | .23 | .47 | 1.30 |
| Electric energy at 2¢ per kw.-hr. | 1.37 | 2.81 | 7.32 | 1.37 | 2.81 | 7.32 |
| Total cost of electric lighting | $ 3.60 | $ 5.59 | $11.33 | $ 3.60 | $ 5.59 | $11.33 |
| Total annual cost of nat. and elec. lighting | $18.51 | $20.50 | $26.24 | $15.72 | $17.71 | $23.45 |
| Cost per min. f.c. per hr. per 100 sq. ft. floor | .0879¢ | .0704¢ | .0556¢ | .0747¢ | .0608¢ | .0498¢ |

TABLE VI.

*Cost of Lighting Various Types of Industrial Buildings when the Rather Unusual and Limiting Condition Obtains in which the Entrance of Light is Wholly Unobstructed or the Buildings are Spaced Very Far Apart and No Real Estate is Chargeable Against the Natural Lighting System.*

The windows are assumed to be washed twice a year.

| | Cost of Lighting per 100 Sq. Ft. of Floor Area for a Minimum of 13 Foot-candles. | | | | | |
|---|---|---|---|---|---|---|
| Building | *A* | *B* | *C* | *D* | *E* | *O* |
| Average Number of Hrs. of Electric Lighting with 200-watt Lamps | 390 | 283 | 209 | 253 | 600 | 2,240 |
| *Annual cost of natural lighting:* | | | | | | |
| Windows and structure | $ 0.44 | $ 1.91 | $ 3.15 | $ 6.35 | $ 0.32 | $ 0.00 |
| Heating | 3.06 | 5.42 | 6.71 | 5.69 | 2.28 | 0.00 |
| Real estate | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Washing windows twice | 1.30 | 1.82 | 1.64 | 1.51 | .96 | 0.00 |
| TOTAL | $ 4.80 | $ 9.15 | $11.50 | $13.55 | $ 3.56 | $ 0.00 |
| *Annual cost of electric lighting for a min. of 13 f.c.:* | | | | | | |
| Lamp renewals—(200 watt) | $ 0.26 | $ 0.19 | $ 0.14 | $ 0.17 | $ 0.40 | $ 1.50 |
| Electric energy at 2¢ per kw.-hr. | 1.56 | 1.13 | .84 | 1.01 | 2.40 | 8.96 |
| Int., dep., etc., and six lamp cleanings | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| TOTAL | $ 4.13 | $ 3.63 | $ 3.29 | $ 3.49 | $ 5.11 | $12.77 |
| Total ann. cost of natural and electric lighting | $ 8.93 | $12.78 | $14.79 | $17.04 | $ 8.67 | $12.77 |
| Cost per min. f.c. per hr. per 100 sq. ft. floor area | .0306¢ | .0438¢ | .0507¢ | .0585¢ | .0297¢ | .0438¢ |

TABLE VI (*Continued*).

| | Cost of Lighting per 100 Sq. Ft. of Floor Area for a Minimum of 21 Foot-candles. | | | | | |
|---|---|---|---|---|---|---|
| Building | *A* | *B* | *C* | *D* | *E* | *O* |
| Av. no. of hrs. of elec. lighting per yr. with 300-watt lighting-units | 660 | 447 | 302 | 390 | 1,065 | 2,240 |
| Ann. cost of natural lighting | $ 4.80 | $ 9.15 | $11.50 | $13.55 | $ 3.56 | $ 0.00 |
| " " " electric | 7.38 | 5.87 | 4.84 | 5.47 | 10.24 | 18.55 |
| Total ann. cost of natural and electric lighting | $12.18 | $15.02 | $16.34 | $19.02 | $13.80 | $18.55 |
| Cost per minimum foot-candle per hr. per 100 sq. ft. of floor area | .0259¢ | .0319¢ | .0347¢ | .0404¢ | .0293¢ | .0394¢ |

### WINDOW OBSTRUCTIONS AND REAL ESTATE AS COST FACTORS.

If it were possible to have light-courts of infinite width without cost we would have ideal conditions for cheap natural lighting. With a view of determining the combined influence of these two factors, computations have been made of the costs of natural and electric lighting for each of the types of buildings investigated with no window obstructions and with no charge for light-courts. The results are presented in Table VI.

### COST OF LIGHTING VERSUS FREQUENCY OF WINDOW WASHING.

In order to investigate the economic advantage of frequent window washing, the annual costs of natural and artificial lighting were computed for Buildings *A*, *B*, and *C*, for one window washing a year instead of two and the results presented in Table VII.

TABLE VII.

*Decrease in the Annual Cost of the Natural Lighting per 100 Square Feet of Floor Area Due to the Practice of Washing the Windows Once a Year Instead of Twice, Compared with the Increase in Annual Cost of Electric Lighting when the Cost of Washing a Square Foot of Window on Both Sides is 1.5 Cents and the Cost of Electric Energy is 2 Cents per Kw.-hr.*

| | Comparative Annual Changes of Costs of Natural and Electric Lighting Due to One Window Washing a Year Instead of Two. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Min. foot-candles..... | 5.5 | 9.4 | 13 | 21 | 38 | 59 | 85 | 133 |
| *Building A* | | | | | | | | |
| Decrease in cost of natural lighting..... | $.65 | $.65 | $ .65 | $ .65 | $ .65 | $ .65 | $ .65 | $ .65 |
| Increase in cost of electric lighting..... | .21 | .68 | 1.37 | 1.77 | 2.51 | 2.83 | 2.57 | .00 |
| *Building B* | | | | | | | | |
| Decrease in cost of natural lighting..... | $.91 | $.91 | $ .91 | $ .91 | $ .91 | $ .91 | $ .91 | $ .91 |
| Increase in cost of electric lighting..... | .13 | .22 | .68 | 2.31 | 4.48 | 3.01 | 3.31 | .57 |
| *Building C* | | | | | | | | |
| Decrease in cost of natural lighting..... | $.82 | $.82 | $ .82 | $ .82 | $ .82 | $ .82 | $ .82 | $ .82 |
| Increase in cost of electric lighting..... | .08 | .16 | .32 | 1.06 | 4.35 | 7.60 | 7.12 | 2.31 |

As may be observed, the advantage is in favor of two window washings a year instead of one, for Building *A* for a minimum intensity of illumination upon the work-plane of more than about 10 foot-candles; for Building *B*, for more than 15 foot-candles; and for Building *C*, for more than about 20 foot-candles.

### INFLUENCE OF ENERGY COST ON LIGHTING COSTS.

There is an energy rate for every level of illumination below which it is cheaper to make no provision or at least make no extra expenditure to procure natural lighting but rely solely upon artificial lighting. As shown in Table VIII,

TABLE VIII.

*Cost of Electric Energy Below Which It is Cheaper to Have a Building of Equal Size without Windows or Light-courts and Illuminated Solely with Artificial Light, Rather than a Standard Building Illuminated with a Combination of Natural and Electric Lighting.*

Windows of each type of building are assumed to be washed twice a year.

| | Cost of Electric Energy in Cents per Kw.-hr. Below Which It is Cheaper to Have a Simpler Building with Electric Lighting Alone. | | | | | | |
|---|---|---|---|---|---|---|---|
| Min. foot-candles | 5.5 | 9.4 | 13 | 21 | 38 | 59 | 85 |
| *With 20-ft. light-courts at $.40 per sq. ft.:* | | | | | | | |
| Building *A* | $2.68 | $1.83 | $1.50 | $1.41 | $1.50 | $1.89 | $3.30 |
| " *B* | 4.70 | 3.15 | 2.40 | 1.80 | 1.95 | 3.16 | 5.10 |
| " *C* | 5.51 | 3.64 | 2.73 | 1.83 | 1.29 | 1.29 | 2.28 |
| " *D* | 6.44 | 4.28 | 3.22 | 2.19 | 1.72 | 2.21 | 6.23 |
| *With 20-ft. light-courts at $0.00 per sq. ft.:* | | | | | | | |
| " *A* | 2.15 | 1.45 | 1.18 | 1.10 | 1.17 | 1.48 | 2.66 |
| " *B* | 4.19 | 2.80 | 2.12 | 1.58 | 1.72 | 2.80 | 4.56 |
| " *C* | 5.19 | 3.43 | 2.56 | 1.71 | 1.20 | 1.20 | 2.14 |
| " *D* | 6.17 | 4.10 | 3.07 | 2.08 | 1.63 | 2.10 | 6.10 |
| *With 80-ft. light-courts at $.40 per sq. ft.:* | | | | | | | |
| Building *F* | | 4.19 | 3.60 | 3.60 | | | |
| *With 80-ft. light-courts at $1.50 per sq. ft.:* | | | | | | | |
| Building *F* | | 5.23 | 4.52 | 4.51 | | | |

TABLE VIII (*Continued*)

*Various widths of light-courts at $.40 per sq. ft.*

| Width of Light-court in Feet..... | 30 | 40 | 60 | 80 | 100 | 150 |
|---|---|---|---|---|---|---|
| Bldg. *E* for 9.4 min. ft.-candles | | | | 1.85 | | |
| " " " 13 " " " | 3.68 | 2.81 | 2.00 | 1.76 | 1.66 | 1.70 |
| " " " 21 " " " | 4.43 | 2.78 | 2.16 | 1.81 | 1.67 | 1.66 |

*Various widths of light-courts at $1.50 per sq. ft.:*

| | | | | | | |
|---|---|---|---|---|---|---|
| Bldg. *E* for 9.4 min. ft.-candles | | | | 3.00 | | |
| " " " 13 " " " | 4.36 | 3.65 | 2.92 | 2.86 | 2.98 | 3.60 |
| " " " 21 " " " | 5.36 | 3.61 | 3.16 | 2.95 | 3.01 | 3.62 |

*Infinite width of light-court without cost:*

| Buildings..... | *A* | *B* | *C* | *D* | *E* |
|---|---|---|---|---|---|
| For 13 min. ft.-candles..... | .96 | 2.00 | 2.50 | 3.07 | .75 |
| " 21 " " " ..... | .66 | 1.35 | 1.62 | 2.08 | .65 |

this rate has been computed for each type of building under a great variety of conditions as to minimum intensity of illumination, width of light-court, cost of real estate, etc.

Judged merely from a standpoint of economy in lighting when the conditions of operation are approximately an average, it appears uneconomical to have a single-story building equipped with more than the simplest side windows unless energy costs more than 1.4 cents per kw.-hr., or to have it equipped with monitor windows unless energy costs more than 1.8 cents per kw.-hr., or to have sawtooth windows unless energy costs more than 2.2 cents per kw.-hr. From a similar standpoint, it appears uneconomical to have the light-court surrounding a six-story building of a greater width than its height when real estate costs $.10 per sq. ft., unless electric energy costs more than 1.5 cents per kw.-hr.; or when real estate costs $.40 per sq. ft., unless electric energy costs more than 1.7 cents per kw.-hr. or when real estate costs $1.50 per sq. ft., unless electric energy costs more than about 2.9 cents per kw.-hr.

### INFLUENCE OF THE NUMBER OF WORK-HOURS PER DAY ON LIGHTING COSTS.

In order to study the influence of the number of work-hours per day upon lighting costs, the annual costs of lighting

Building *D* to a minimum intensity of 21 foot-candles have been computed for one, two and three shifts of labor per day. The building is assumed to be spaced a distance of 20 feet from other buildings of similar height but no charges are made against natural lighting for light-courts. With but one shift of labor per day, work begins at 7:30 A.M. and ends at 4:30 P.M.; with two shifts a day, work begins at 6:00 A.M. and ends at midnight; and with three shifts a day, each shift is on duty eight hours a day. With the windows washed semi-annually, a lighting-unit operates on an average of about 390, 2,390 and 3,970 hours per year respectively with one, two and three shifts a day. Electric energy is assumed to cost two cents per kw.-hr.

Under the conditions stated and for the items considered, the annual costs of natural light per 100 sq. ft. of floor area and the costs of the artificial light needed to supplement the natural light in maintaining a minimum of 21 foot-candles upon a horizontal work-plane three feet above the floor are:

| | One Shift a Day. | Two Shifts a Day. | Three Shifts a Day. |
|---|---|---|---|
| Annual cost of natural lighting | $13.55 | 14.11 | 14.80 |
| Annual cost of artificial lighting | 5.47 | 19.62 | 30.78 |
| Total | $19.02 | 33.73 | 45.58 |

## SUMMARY.

With the growth of the science of light and vision, the engineer has been putting forth some effort to use daylight to a greater advantage. In our endeavor to use natural and artificial light in a more economical manner, it becomes necessary to know the initial and operating costs of each. The determination of the initial cost of natural lighting is made by computing the difference in cost between a building equipped with natural and artificial lighting and a building of similar construction equipped merely with artificial lighting.

Though it may be possible to dispense with natural lighting, it would hardly be possible to dispense with artificial lighting if work is to be pursued for eight hours a day through-

out the year; for natural light is of no greater constancy than daylight itself.

The major items entering into the initial cost of natural lighting equipment per 100 sq. ft. of floor area under normal conditions vary from a minimum in one type of standard building to a maximum in another type as follows:

| | Minimum. | | Maximum. |
|---|---|---|---|
| Windows and structure | $ 0.00 | to | $45.00 |
| Heating equipment | 10.30 | " | 32.10 |
| Light-courts | 8.40 | " | 45.30 |
| Total for all three items for standard buildings | 28.56 | " | 79.90 |

The investment cost of heating equipment to supply heat losses incident to windows varies from $.32 to $.45 per sq. ft. of window surface for buildings having side windows only, and from $.41 to $.59 for buildings having windows in the roof also.

The annual cost of maintaining and operating the heating system to supply heat losses incident to windows varies from a minimum of 7 cents per square foot of window surface in Building *A* to a maximum of 12.3 cents in Building *C*.

The initial total cost of electric lighting equipment per outlet or per 100 sq. ft. of floor area with lighting-units spaced on 10-foot centers, varies from $10.20 for 5.5 foot-candles on the work-plane to $17.50 for 38 foot-candles.

Under average conditions the ratio of the initial costs of natural to electric lighting equipment varies from 2.25 for a single-story flat roof building to 6.3 for a sawtooth building.

Under the same conditions the ratio of the annual cost of natural lighting to the annual cost of electric lighting varies from 1.09 for a single-story, flat roof building to 4.03 for a sawtooth building.

For a minimum intensity of illumination of 13 foot-candles upon the work-plane the average time a lighting-unit operates a year varies from 651 hours for a single-story, flat roof building to 253 hours for a sawtooth building. For a minimum of 13 foot-candles, the average time a lighting-unit operates per year in a six-story building surrounded by buildings of its own height varies from 918 hours for 150-foot light-courts to 1,762 hours for 30-foot light-courts.

The combined cost of natural and artificial lighting per

hour per minimum foot-candle upon the work-plane attains a minimum at about 38 foot-candles for most types of standard buildings.

Since the cost of heat loss due to windows is generally offset by the cost of electric energy saved by the incoming light, it would seem usually justifiable to equip industrial buildings with simple side windows. However, it would seem unjustifiable from a viewpoint of economy in lighting to incur a great expense for light-courts, or windows in the roof of the building unless the minimum intensity of illumination upon the work-plane is to exceed about 15 foot-candles.

It appears that a practice of washing windows less frequently than twice a year is uneconomical excepting when the minimum intensity of illumination upon the work-plane is maintained at less than 10 foot-candles.

When determined merely by the cost of lighting, it appears from these results that for any type of standard building investigated and operating under average conditions that no appreciable expenditure for natural lighting equipment is justifiable when electric energy can be purchased as low as 1.4 cents per kw.-hr.

# PLASTIC CELLULOSE IN SCIENTIFIC RESEARCH.*

BY

K. HICKMAN AND D. E. HYNDMAN.

Experimenters in the time of Newton or Priestly were proud to boast that, from a jam jar, some string, and a piece of sealing wax, they could construct almost anything.

Nowadays, although our laboratories are supplied with a great variety of intricate devices and pieces of glassware, nearly every chemical and physical problem demands the construction of some special apparatus. The methods at our disposal vary with our constructive skill, but rarely embrace more than:

Carpentering,
Glass blowing,
Soldering and sheet metal working,
Plumbing,
Elementary electric wiring.

Of these, with the advent of Pyrex, it may be said that glass working is by far the most useful, and the least dispensable. To be able to see what is happening inside the apparatus is the great advantage, outweighing a hundred minor drawbacks. If metal working could produce transparent articles, the value of soldering and plumbing would be enormously enhanced, and many experimental problems would be simplified. This article does not describe such a miracle, but it does compromise by showing how transparent cellulose compounds may be built into useful laboratory apparatus.

Transparent cellulosic sheeting is generally made from cellulose nitrate or cellulose acetate. The more usual nitrate material is commonly known as celluloid. Since, however, this is a trade name for a special product, we shall speak of the material as pyroxylin;[1] and refer to cellulose acetate sheeting as acetate base.

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* Communication No. 370 from the Kodak Research Laboratories.

[1] Plasticized nitrocellulose sheeting.

A word as to the properties of these two substances: Pyroxylin is a mixture of cellulose nitrates plasticized with camphor. It is not only inflammable, but it also decomposes in the absence of air. Decomposition begins between 140–170° C. and inflammation occurs at a higher temperature. Below the boiling point of water it softens sufficiently for moulding.

Acetate base, on the other hand, since it contains no camphor, is not so plastic or easily moulded. It can be bent at 100° C. and will retain its new shape. It does not decompose spontaneously in the absence of air at temperatures below its ignition point, and it does not burn with special vigor. Hence, its use for safety cinematograph film and home motion pictures. Both materials are softened by certain organic solvents and two pieces may be stuck together by placing a drop of solvent between and squeezing into contact. The solvent softens and partially dissolves the surfaces and is then absorbed by the mass of the material, as water is absorbed by gelatin. Later it evaporates. The process, however, can produce a perfectly autogenous weld of a strength equal to that of the original material.

Pyroxylin and acetate base may therefore be bent and welded into the most complicated shapes. Since they may be stuck to glass, elaborate apparatus may be built up of dimensions impossible with glass tubes alone. Examples will be described later.

Besides the inability to resist heat, neither material will withstand strong liquids. The vague term "strong liquids" may be interpreted as:

| *Pyroxylin* | *Acetate Base* |
|---|---|
| Concentrated nitric acid | Moderately concentrated acids |
| Concentrated hydrochloric acid | 2 per cent. alkali |
| Concentrated sulfuric acid | Acetone |
| 10 per cent. or stronger caustic alkali | Alcohol |
| Acetone | Ether |
| Alcohol | Amyl acetate |
| Amyl acetate | |

Both will stand water, solutions of metallic salts, dilute acids, carbonates, benzene, chloroform, and xylene. Pyroxylin will resist 20 per cent. sulfuric acid indefinitely.

CONSTRUCTION WITH PYROXYLIN.

The operations involved are four in number and are extremely simple. They are:

(1) Cutting
(2) Shaping
(3) Welding:
    (*a*) to like material,
    (*b*) to glass and other substances.
(4) Laminating.

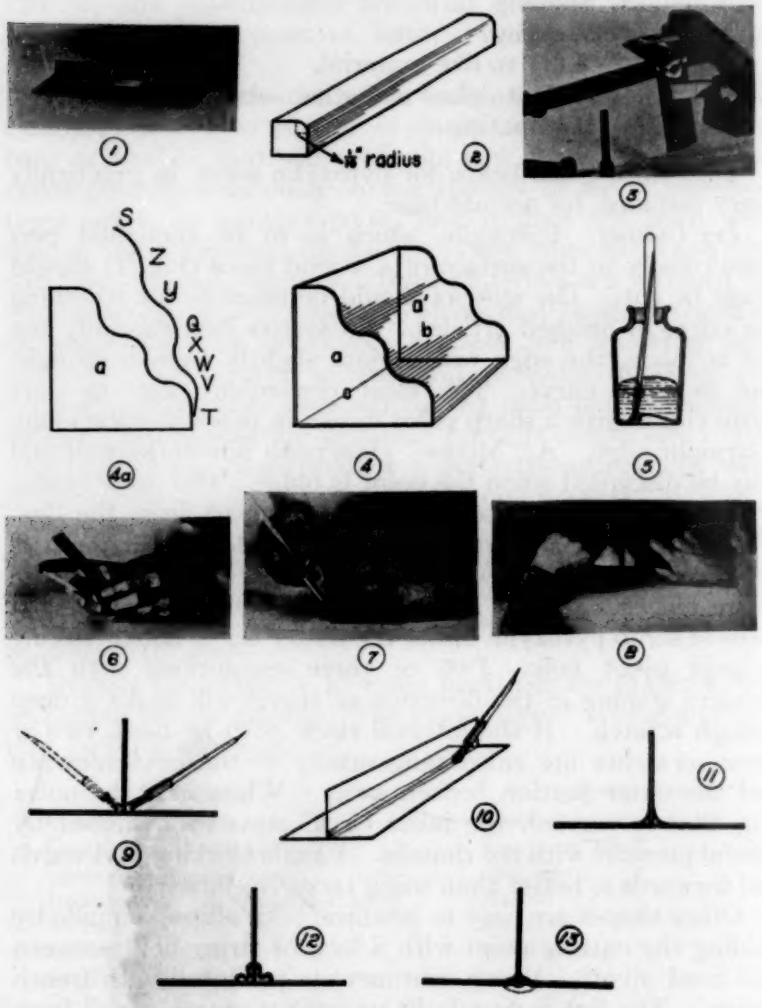
Directions given below for pyroxylin serve, in practically every instance, for acetate base.

(1) *Cutting.* Pyroxylin which is to be cemented perpendicularly to the surface of a second piece (Fig. 1) should never be cut. The scissors should be reserved for trimming the edges of finished articles. No matter how carefully the cut is made, the edge will deviate slightly from a straight line or pure curve. The most convenient way to part pyroxylin is with a sharp point drawn in pencil fashion along a straight edge. A "Moore" glass push pin works well and may be discarded when the point is blunt. Old razor blades are not suitable because they tend to depart from the line. When a good clean scratch has been made, the material is bent backwards until, with a slight crack, it parts along the entire length. Circles are cut with the dividers, placing a piece of scrap pyroxylin under the center leg to avoid making a large pivot hole. Two or three revolutions with the dividers leaning in the direction of travel will make a deep enough scratch. If the internal circle is to be used, two or three scratches are ruled tangentially to the circumference and the outer portion broken away. When it is the outer ring that is wanted, the inner circle must be detached by careful pressure with the thumbs. Gentle working backwards and forwards is better than using excessive force.

Other shapes are easy to produce. An ellipse is made by guiding the cutting point with a loop of string held between two fixed pivots. Wavy contours are produced with french curves. The line is first built up with a grease pencil from various positions of the curve and is then retraced, still using the curve, with the sharp point.

(2) *Shaping.* The many cellulose nitrate articles available commercially are evidence that with moulds and dies any shape can be produced. Moulds are not common in the

FIGS. 1–14.




laboratory so that the shaping operation is limited to simple bending. Variations of the cube and cylinder are possible, but not the sphere.

There are three requisites for bending: a square metal bar, a selection of metal rods, and a vessel of hot water. The metal bar is by far the most useful.

The inflammable nature of pyroxylin would suggest using hollow bars and tubes which could be warmed with steam from an electric kettle. We have found it safe, however, to use a Bunsen burner, making sure that the pyroxylin and cement are pushed out of the way.

The bar has available four edges and four sides. At least one edge should be rounded, forming part of a circle of about 1/16-inch radius (Fig. 2). All four sides may be at right angles, or the bar may be a right-angled triangle. In this case the other two angles should be rounded as well. The bar is going to supply heat to the pyroxylin, and no matter how sharp a bend it is desired to make, there must be sufficient bearing surface to convey the heat.

The bar is warmed by waving the Bunsen flame along its length until the moistened finger just sizzles when touching the upper surface. The flame is now extinguished and the pyroxylin brought into contact. A line should previously have been ruled with the grease pencil where the bend is to come. On no account must a scratch be made. The pyroxylin is grasped by the ends with the two hands, and when it has begun to yield, the regions near the bend should be pressed with wood strips, or smothered tightly with a cloth. When the desired angle has been reached, the sample is removed, taking care to maintain the angle until cold (Fig. 3). The procedure is similar when making a less sharp bend around a rod.

Sometimes it is necessary to produce an irregular shape to fit some special contour. In Fig. 4 the pieces $a$–$a'$ are similar and have two edges at right angles, while the third follows the special contour; $a$ and $a'$ form the side pieces to the angular strip $c$. Let us suppose it is necessary to bend $b$ so that it may be cemented in place to complete the box. $b$ is cut in a strip ¼ inch wider than called for and at least an inch longer. Placing the piece $a$ beside a bowl of water hotter than the hands can bear, $b$ is held with pliers and immersed. In a minute it is withdrawn and given a quick pressure with the hands at $V$ and allowed to spring away

again. It will have taken a slightly permanent shape. If it does not match the curve of *a* sufficiently, the warming and pressing are repeated until a slightly *exaggerated* bend is secured. The curves at *W*, *X*, *Y*, and *Z* now receive attention, exaggerating each one, in order, a little less than its predecessor. In this way the final sample is found to have curves at the right places but owing to recovery in warm water each curve is a little *less* pronounced than needed. This is an advantage, for when fixture is made at the point *T* (Fig. 4*a*), pressure at *S* brings the whole strip into contact with *a* and allows the cementing to be accomplished in one operation.

(3) *Welding.* (*a*) *Autogenous: Pyroxylin to Pyroxylin.* The requirements are *thin cement*, and *thick cement* in suitable containers, and some *hog's hair brushes*, in holders from which the varnish has been scraped. The containers are easily made from 6-ounce wide necked bottles supplied with large corks which do not fit too tightly. Through a central hole in each cork a stout walled test tube ¾ inch in diameter and 6 inches long is pushed from below. This is much better than having the brush itself fixed in the cork (Fig. 5).

Many formulas for film cement have been published, but since small quantities only are needed, we have found it convenient to use the ready-made Eastman cement without inquiring into its composition. This is the thin cement referred to above.

The thick variety is made by dissolving scrap pyroxylin, cut in strips an inch and a half long by 1/16-inch wide, in the thin cement. A spare bottle is filled one-third full of the chips and cement poured in until the bottle is more than half filled. The mixture is stirred vigorously with a stout glass rod every ten minutes throughout the day and left to settle over night. In the morning the clear thick syrup is decanted into the container from a slight residue of gelatinized strips. A brush is selected, placed in the syrup, and the cork thrust home.

It should be understood at the outset that pyroxylin sticks to itself by virtue of its own powers of adherence. The cement is used merely to prepare the surfaces. After these have momentarily been flooded, the best joins are

obtained when the surfaces are pressed together tightly enough to extrude every trace of unabsorbed liquid. Obviously, the thick cement will not be pressed out as efficiently as the thin and will therefore not make as good a join. The thick fluid must never be used except for external reinforcement of the join.

Joins are of two kinds, perpendicular and parallel, or end to face and face to face. The latter is lamination on a small scale.

The parallel join is very easy. One sample is stood at an angle on the other and a few drops of cement from a pipette or a brush are laid in position. The upper sample is quickly laid down and an even pressure applied all over with the flat of the hand or a cloth pad. A piece of blotting paper underneath will absorb excess cement pressed from the edges. The operations are shown in Figs. 6 and 7, while the finished join is being tested in Fig. 8.

The perpendicular join is more difficult but much more useful. At its simplest, the straight edge of a piece of pyroxylin is pressed tightly against a pyroxylin surface, while a little thin cement is run along the angle at each side (Fig. 9). The pressure is maintained for 30 seconds after all trace of liquid has disappeared and the sample left undisturbed for an hour. It is then held in an inclined position (Fig. 10), while a drop of thin cement is placed at the top of the angle on each side and allowed to run down, which it should do quickly. Immediately a big drop of thick cement is placed in the same position and allowed to fall slowly along each crevice. At every inch or two of fall it should be replenished, not at the top, but at the head of the traveling drop. Finally the sample is put away to dry for one day on a level surface, after which a section of the join should present the appearance in Fig. 11. The object of the pre-wetting with thin cement is to prevent the inclusion of air bubbles.

If the thick cement had been applied to the corner with a brush, it would have formed ridges where it was least needed, yielding a finished product like Fig. 12.

The reinforcing cement must be used with caution. It sets after partial drying into the shape of the join, but later when more solvent has evaporated, it contracts and pulls the

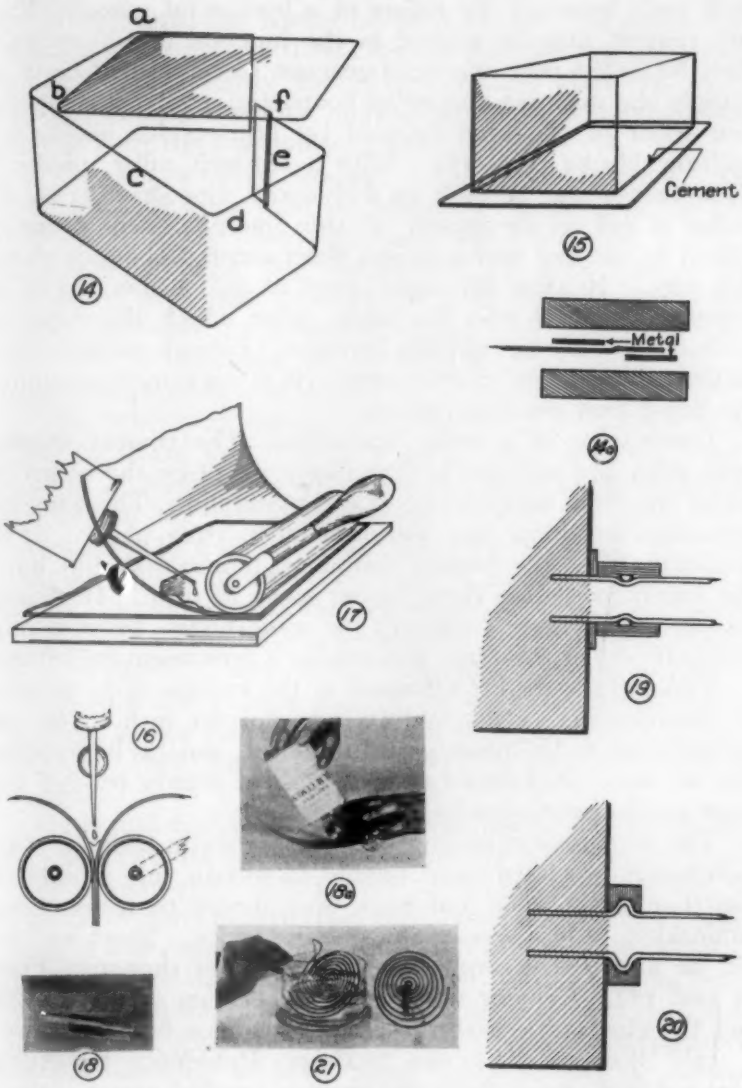
pieces to a more acute angle than was intended. The reinforcing must always be done on two sides of the join and sometimes, if the appearance of Fig. 13 is to be avoided, on three. The properly finished join is shown in Fig. 11.

Most perpendicular joins are less simple. They are the kind involved when an end, a side, or a partition is cemented in a shaped container. Fitting a circular disk into the end of a cylinder is perhaps the simplest case. The disk, cut to fit tightly, is pushed into place and thin cement run all round. Since there is no tendency for the join to come apart, the thick cement may follow immediately. A large tear is placed in one crevice and the cylinder rotated until the syrup has fallen all around. The other side is then treated.

Fastening the end into a rectangular box is a little more difficult. The sides of the box may be completed before or after insertion of the end. In the first case the end piece is cut accurately to size but the corners are rounded off more than would appear necessary. It is thrust into position and cement applied at the center of the long sides, holding them against the end piece for at least a couple of minutes. The centers of the short sides next receive treatment and cement is finally brushed all around. One hour must elapse before the application of thick cement.

When the rectangular box has to be built around the end piece, it should be fitted by trial and error before any cementing is done. The join is most conveniently in the middle of a long side. Cementing of the top plate is begun with one-half of the split long side (*a* in Fig. 14), being careful that the plate is pushed snugly up to the corner. After a few minutes, sides *b*, *c*, and *d* may be brought into position and secured. Finally side *e*, previously given a rebate *f* by pressing between two thin metal plates in a vise (Fig. 14*a*), is cemented in place and a parallel joint made all the way down. If necessary, the operation on this end plate may be repeated step by step on another plate at the other end, thus forming a closed box. The simplest way of all of closing the rectangle is to stand it on a plate larger than actually required, run cement all around the crack, and follow this, within and without, by thick cement (Fig. 15).

FIGS. 14–21.




(4) *Lamination.* Although joining pyroxylin to glass and other materials is next in order for consideration, it will be convenient first to describe lamination.

If two thin pyroxylin sheets are placed face to face, with their ends between the rollers of a horizontal mangle (Fig. 16), cement may be poured in the junction and they may then be rolled into one homogeneous piece. In place of a mangle one may use a drawing board and a gelatin composition roller of the kind favored by printers for inking up halftone blocks (Fig. 17). With a ten-inch roller, pieces 9 by 20 inches may be built up with ease. One sheet 11 by 25 inches is laid on the board. A thin line of cement drops is placed at one end and a second sheet secured above it along this edge. Holding the upper sheet at 45°, a liberal pool of cement is poured into the angle, after which the roller is pushed smoothly but quickly forward. Enough cement must be used to stick the entire length. It is convenient to squirt the liquid from the original can.

Laminating is a messy operation. The cement exudes from sides and end and is very likely to get on the board or under the clean bottom face of the pyroxylin. This may be prevented by doing the operation on blotting paper. It is important that the freshly laminated material should have the uncemented side portions cut away at once. It should be allowed to hang vertically for some hours, because any bend suffered at this stage will impose a permanent curvature.

Pyroxylin is readily obtained in thicknesses of 5, 10, and 20 thousandths (1/200, 1/100, 1/50) of an inch. The 20 thousandths is the most useful material, and by laminating two or three thicknesses of this, a sheet sturdy enough for most requirements can be made.

The need is soon encountered for pyroxylin tubing. Unfortunately we have been unable to obtain this in lots of less than 50 pounds, and have been forced to make it by lamination, or else press glass tube in service. Short lengths can be made very simply after the manner shown in Figs. 18 and 18*a*. Cement must not get between the pyroxylin and the glass, otherwise the mandrel cannot be withdrawn.

(3*b*) *Welding Pyroxylin to Other Materials.* Pyroxylin does not make good shafts or bearings, or good narrow tubes. Whenever moving parts are involved, or fluids have to be conveyed to containers, glass or metal spindles or tubes have to be fixed to the pyroxylin.

Pyroxylin cemented to smooth glass or metal adheres fairly well until one corner becomes lifted. Then any slight strain strips it away. This happens particularly easily under water. Consequently the pyroxylin and glass (or metal) have to be shaped so that one surrounds the other completely and without the possibility of rotation.

*Cementing a Glass Tube into a Pyroxylin Container.* Two methods have been used successfully. In the first the glass is indented in the blow pipe flame and when cold, a chip of pyroxylin is thrust into the cavity. A thick tube is then laminated over this, wetting the glass with much cement. When the walls are a quarter of an inch thick, the whole assembly is cemented to the side of the vessel. Fig. 19 shows the procedure in detail.

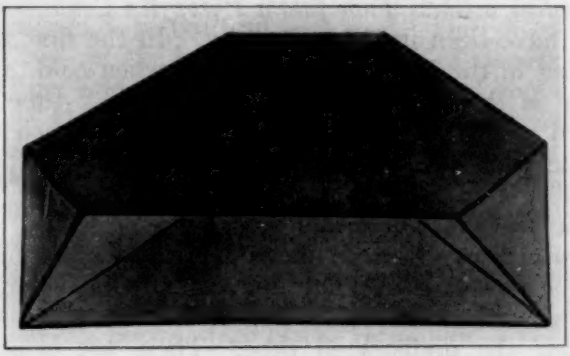
The other way uses an unsymmetrical expansion in the glass to secure grip. A flat uneven bulb is blown, and a number of washers are cut to fit its contours, the outer ones just fitting the undistorted tube. These are cemented in position one by one, giving the effect shown in Fig. 20. Such built up collars give extremely strong joins. Shafts may be pushed through pyroxylin Pelton wheels, or film developing drums, and secured at each contact by some modification of the procedure. Good contact can often be secured between a glass tube and a single plate of the rotor by merely denting the glass at the junction and painting it liberally with thick cement. This dries into the hollow and produces firm adhesion.

Steel and copper offer no especial difficulties except that the cement must on no account contain acetic or other acid.

A device which has proved useful is shown in Fig. 21. A spiral of narrow pyroxylin tube was wanted. Accordingly a coil of fine copper piping, having an outside diameter equal to the internal diameter of the finished pyroxylin, was wound into a well-spaced spiral, and supported by a wire handle. It was then dipped about 30 times into thick pyroxylin cement, allowing at least three hours for drying between successive dips. The dipping required rigid adherence to a certain sequence of operations. First the spiral was dipped with a slanting motion into thin cement and quickly withdrawn. It was then instantly lowered *slowly* in a slanting

manner into the thick cement. When under the surface it was rotated through 180° and removed at an angle, being careful that each convolution left the surface without forming a drop. Once out in the air it was rotated in all

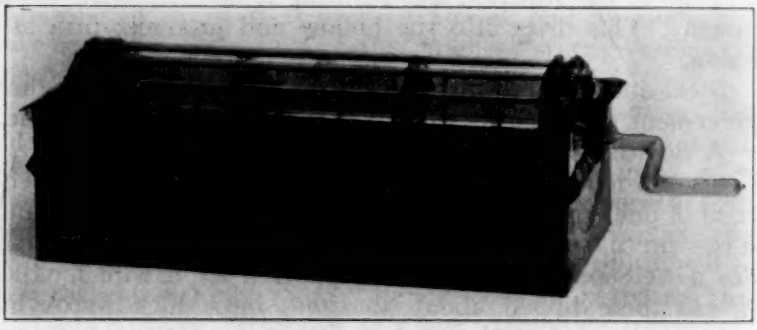
FIG. 22.



directions for a minute or two until the new layer had set. It was then hung up to dry.

After the thirtieth coat, a day's drying was given in the 60° C. oven. The copper spiral was then dissolved out with

FIG. 23.

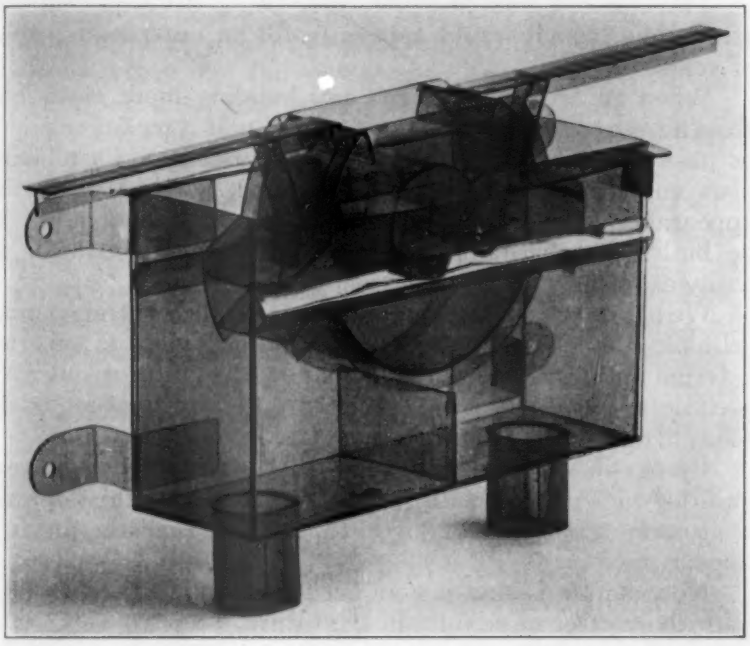


1 : 1 nitric acid. This was a tedious operation owing to the gases driving the acid out of the spiral. It has to be done quickly or degradation of the pyroxylin sets in. Finally when the copper was entirely removed, a mixture of water

with 25 per cent. of industrial alcohol was drawn through, a few c.c. per minute, for a day. The spiral, when dried, served its purpose excellently. One is shown, minus the copper core, at the right of Fig. 21.

*Strength and Rigidity.* Thin pyroxylin sheet is too flexible to give mechanical rigidity unless it is bent and secured in many directions. A careful design will include sufficient

FIG. 24.



cross pieces. When these are not admissible, right-angle struts and bracings may be put across the straight sides. They will be observed in many of the later figures.

*Tinting.* Pyroxylin may be colored by dissolving dyes in a mixture of alcohol and acetone. The particular mixture of solvents must be found to suit the individual worker. Generally speaking, the more acetone, the more strongly the color will take.

*Sphere of Usefulness.* In the laboratory we have found pyroxylin construction invaluable in making:

Models of crystals and atoms where it is desired to see top, bottom, and contents all at the same time (Fig. 22).

Film developing drums in those photographic researches where it is inadvisable to let the developer touch anything but glass and film substance (Fig. 23).

Containers in hydraulic systems where it is necessary to observe the path taken by water.

Certain industrial instruments where the solutions attack all materials but pyroxylin (Fig. 24).

There is one use, however, now being developed in our spare time, which would appear to fill an outstanding need of years.

When an architect designs any building more ambitious than a four-room villa, he is forced to build a model of paper or pasteboard to satisfy his patron's curiosity. Pasteboard does not allow the interiors to be seen, so that when the appearance of these is in question, a special section has to be built. Furthermore, pasteboard is not so plastic or so easily assembled as pyroxylin.

We have experimented in building a cottage in transparent cellulose, and find it possible, besides giving a superior external finish, to show the layout of the interior down to such details as upper floors, stairs, fireplaces, radiators, bathroom fittings, and even furniture.

Pyroxylin is easily tinted and thus the roof may be red, and the walls painted with ivy without impairing the essential transparency. This conduces to a most realistic finished appearance.

No example is shown here because it is intended to deal with the matter more fully in the future.

# THE EXPERIMENT IN STATICS.

BY

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Buenos Aires,
Member of the Institute.

THE experience, familiar in almost any field of science, that problems might be easier, quicker and even more accurately solved by the visible experiment than by abstract reasoning only, has largely been overlooked in at least one line of its application of importance in daily life, viz. the calculation of resistance of structures. That calculation so far generally is being based on abstract mathematics with the result that even today a fair approximation to actual conditions in the field is practically unknown, because it would lead to formulas complicated beyond usefulness for application in practical life. It will be of interest to adepts in any field of natural science to learn how statical problems may be solved by one visible, simple experiment, which the mathematical Statics could solve only by numberless equations and formulas.

In my article of July 1926, of the JOURNAL OF THE FRANKLIN INSTITUTE, "Mechanical Calculations of Elastic Systems," I have shown how flexible models of structures will automatically form the influence lines of stresses at any section of the structure, when subjected to such visible displacements at that section, which will occur after those stresses have overcome resistance, that is to say that the stress may be read right from the model, which a load, acting at any other section, will produce in the displaced or disrupted section. I described in that article how in the "Continostat," invented and developed by me for the purpose, models may conveniently be built up of steel splines, which reproduce structures of the daily practice of the engineer, e.g. continuous beams, portal frames and frame buildings of any number of spans and stories, trusses without diagonals, any other structure with members joining at right angle, even

one span arches, etc., altogether not less than 95 per cent. of the cases occurring in the daily practice of the engineer. In the present article, the most interesting and spectacular applications to irregular problems of statics, that is to say, to oblique and compound structures may be illustrated.

### 1. COMMON STRUCTURES.

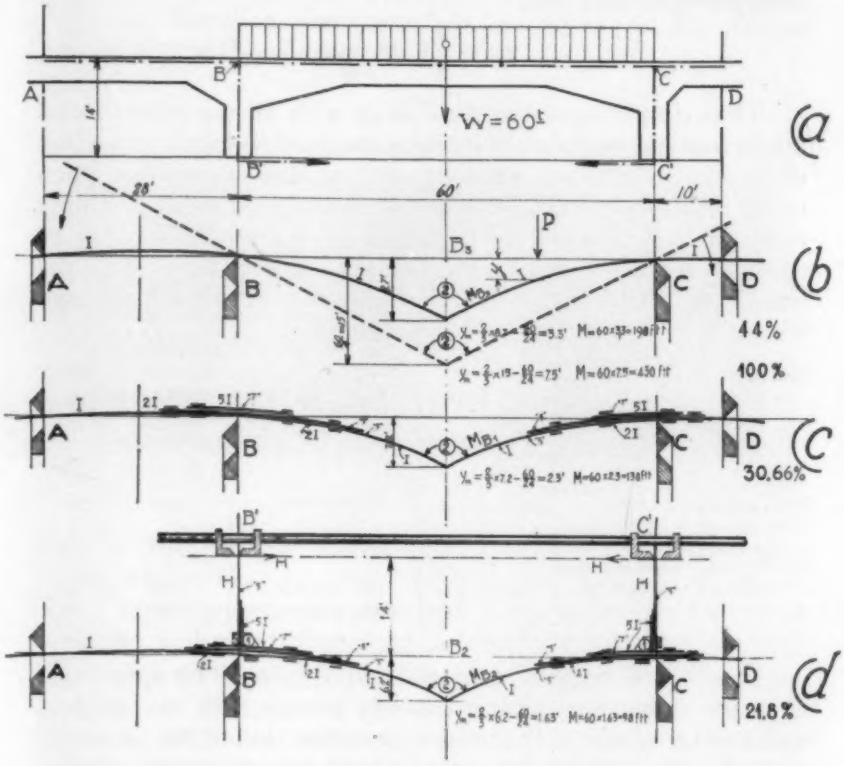
To properly understand the mechanostatical solution of irregular structures by means of visible deformations, it may be well to show first the great scope and importance in technical practice of the theories set forth in the former article, explaining their application to an example from the field. In Fig. 1 is shown the cross section of a reinforced concrete building supported at the ends on party walls and, between them, on two rigidly joined columns, forming spans of 28′, 60′ and 10′ and a total height of floor of 14′. The main span $BC$ is loaded uniformly with a total load of 60 tons. The height in center of $BC$ and consequently the bending moment must be reduced as much as possible to leave greatest clear space possible.

Commonly now the designer would consider the beam $BC$ as freely supported and as a "rule of thumb" deduct any amount between 10 per cent. and 30 per cent. from the bending moment thus obtained and call that Statics. The bending moment for the simple beam would be $M_E = \frac{1}{8}Wl = \frac{1}{8} \times 60 \times 60 = 450$ ft. $t$. The influence line for the bending moment at the center of the freely supported beam $BC$ is shown as the dotted line in Fig. 1$b$, it is a triangle, the height of which in center is $h = \frac{1}{8}l$, the area $F = \frac{1}{8}l^2$ and the average height or ordinate $y_m = F/l = \frac{1}{8}l$.

Suppose now we join two steel splines with the No. 2 clamp of the Continostat so that they will form the broken dotted line in Fig. 1$b$; we hold the broken beam thus formed at $B$ and $C$ and bend the extending ends until they pass through $A$ and $D$. It will easily be seen that by doing that the No. 2 clamp will shift automatically towards $BC$ until the spline will form the heavy line curve shown in Fig. 1$b$, which is the influence line of bending moments $M_E$ at center $E$ of the span $BC$, assuming a constant section of the beam from $A$ to $D$. We may take into consideration now the

increase of section near the supports by simply adding short steel splines near $B$ and $C$, whereupon the influence line will flatten more (Fig. 1*c*); joining further by means of the No. 1

FIG. 1.




right angle clamps at $B$ and $C$ two short splines at right angle, which represent the interior columns, holding the column feet upside down at original distance by means of the sliding rule, the bending moment will be further reduced as shown in Fig. 1*d*.

A concentrated load $P$ acting at any section of the structure will produce then at $E$ the bending moment $M_E = Py$, where $y$ is the ordinate (Fig. 1*b*) of the influence line at $P$. A load $W$ however uniformly distributed over the span $BC$ of $l = 60'$ length will produce the bending moment

$M_E = Wy_m$, wherein $y_m = F/l$ is the average ordinate of the influence area $F$, enclosed by the influence line and the axis $BC$. I have been able to prove that in order to know $F$ it is only necessary to know the ordinate $h$ in center of the loaded length and that

$$y_m = \frac{2}{3}h - \frac{1}{24}l.$$

That simple equation does away with all the complicated mathematical methods of integration used so far; it is mathematically correct for constant section, and nearly so, when beam is reinforced near supports. We obtain then, and may read off the cross section paper, in less time than it takes to describe it, the bending moment at center of beam $BC$, the length of which is $l = 60'$ and therefore $1/24l = 2.5'$, and which is loaded by $W = 60t$, as follows:

| Beam $BC$. | Ordinate $h$. | In Center $2/3h$. | Average Ordinate $y_m = \frac{2}{3}h - \frac{1}{24}l$, feet. | Bending Moment $M_E = Wy_m$. | |
|---|---|---|---|---|---|
| | Feet. | | | Foot-tons. | %. |
| Free supports at $B$ & $C$ . . . | 15 | 10 | 10 − 2.5 = 7.5 | 450 | 100 |
| Continuous, constant section . . . . . | 8.7 | 5.8 | 5.8 − 2.5 = 3.3 | 198 | 44.0 |
| Continuous, sections increased near supports . . . | 7.2 | 4.8 | 4.8 − 2.5 = 2.3 | 138 | 30.7 |
| do. do. fixed columns . . . . | 6.2 | 4.13 | 4.13 − 2.5 = 1.63 | 98 | 21.8 |

It will not require a specialized Engineer to appreciate that the reduction obtained nearly to one-fifth the original value of the stress at the most exposed section of the structure may be of greatest economical and scientific importance. It should further be noted that to obtain those results the way shown in Fig. 1 will not take more minutes than the mathematical stressanalysis requires hours with all the errors possible in abstract mathematical procedures. With variation of story height, of relative spans, etc. results may change entirely and possible rules of thumb based on results as obtained above may easily lead to disaster. It is then the enormous progress and advantage of visible mechanostatical methods in the "Continostat" that they actually permit figuring each case by taking into account its actual conditions.

### 2. DEVICES FOR IRREGULAR STRUCTURES.

Irregular structures in Mechanostatics may be called those structures the members of which joint at oblique angles; that distinction is convenient on account of their entirely different mechanical requirements, from those necessary for common structures as described in the former article and in the chapter No. 1.

FIG. 2.

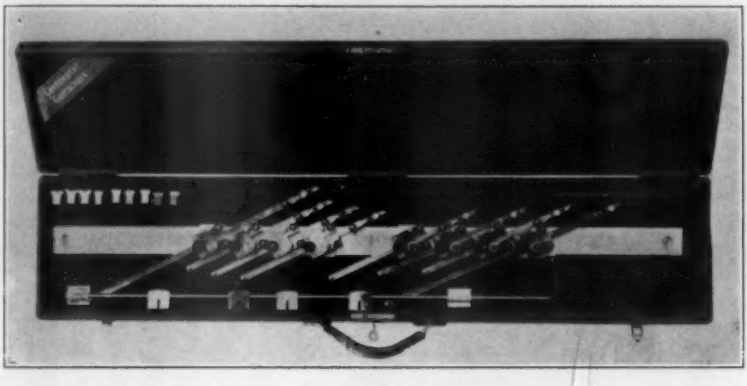


Fig. 2 shows the "Constinostat" used for common structures, whilst Fig. 3 is the "Continostat-A" or "Mechanostat," containing a complete set of devices, which in combination with the "Continostat" make it possible to apply the visible methods developed by me even outside of building work to the complicated structures which occur i.e. in shipbuilding, airplanes, parts of engines etc. As will be more clearly shown in the photographs hereafter the "Continostat-A" consists mainly of attaching devices A-1 and A-5 to the several parts of the "Continostat," of holders and rods A-2, A-3 and A-4, of insert clamps A-7 for tension rods and of ringclamps A-6, the holders of which are automatically held in exact radial direction, but otherwise may freely gyrate or be fixed in any position.

The material of which models are to be composed will preferably be steel splines the same as before; however at irregular structures it frequently has become convenient to use plastic metal splines, which could be bent into shape

by hand, without losing elasticity outside of the sharply bent places. Specially rolled plastic metal splines are therefore being added to the "Continostat-A" to be used for what may be called plastic models. It may be said that generally plastic models give satisfactory results and approximations

FIG. 3.

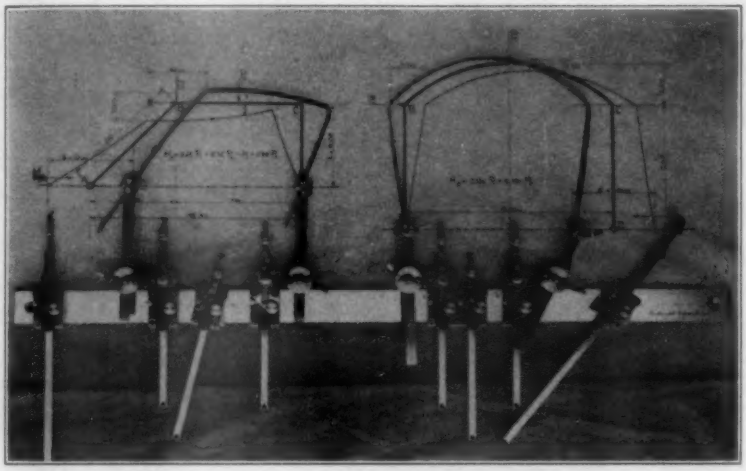
within 5 per cent. of analytical results, although they do not permit as large deformations as do the models composed of steel splines and cannot be deformed as great a number of times as the latter without harm to their elasticity.

### 3. PLASTIC MODELS.

As said before, plastic metal may be bent into shape right on top of the drawing; we also may use combined plastic metal for curved parts and steel splines for straight members, taking into consideration the modulus of elasticity $E$ of the plastic metal is approximately half of that of steel splines. It therefore must have a thickness of $\sqrt[4]{2}$ or very nearly 5/4 of that of steel splines in order to have the same specific resistance to bending. It should be noted that when

model is not bent absolutely true to plan, errors neutralize one another when subjecting models to two equal but opposite displacements each time.

FIG. 4.



In Fig. 4 to the left has been shown an oblique portal frame, to the right a portal with curved beam; the "Constinostat" has been photographed in the position of displacing horizontally the foot of the left and the right column respectively by any distance $s/2$. The slide of the "Constinostat" then, holding the columnfeet in the hinged A-2 heads will be moved by $s/2$ the opposite way in order to obtain the influence line of horizontal thrusts. Taking the arched portal frame to the right of Fig. 4 the resulting thrust $H_A$ at foot of left column and $H_D$ at foot of right column may be read off the plan as follows:

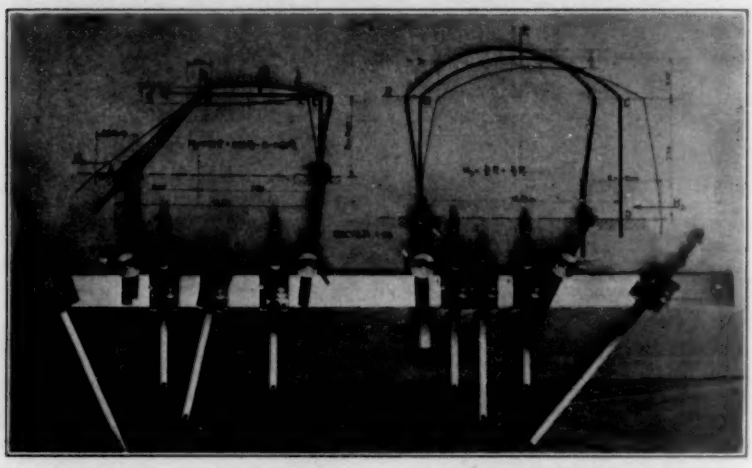
$$H_A = \frac{1.34}{10} P_1 - \frac{10 - 3.95}{10} P_2, \qquad = 0.134P_1 - 0.605P_2,$$

$$H_D = \frac{1.34}{10} P_1 + \frac{3.95}{10} P_2, \qquad = 0.134P_1 + 0.395P_2,$$

1.34 and 3.95 cm. being the distance the model has moved at $P_1$ and $P_2$ respectively when shifting $D$ each way $\frac{s}{2} = 5$ cm.

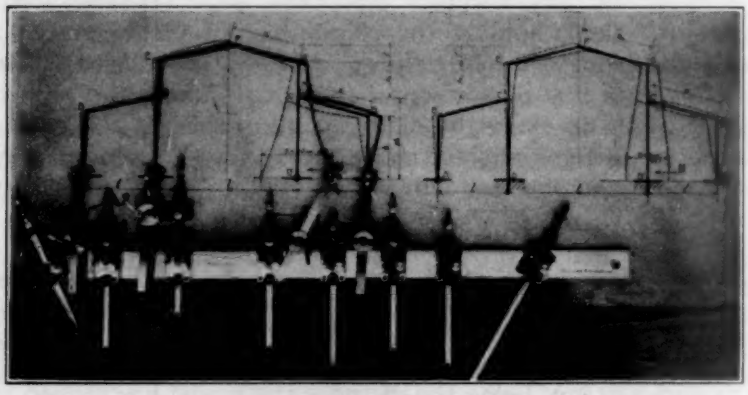
By merely pulling the small lever at the swivel head of the A-2 rods which hold the feet of the columns, those heads may be fixed and when sliding the A-2 rods along the main

FIG. 5.



bar of the "Continostat" the model will automatically mark the influence lines of the horizontal thrust for fixed column

FIG. 6.



feet (Fig. 5). Note the most instructive picture of the difference between influence lines for hinged supports (Fig. 4) and fixed supports (Fig. 5).

Several parts of plastic models can be easily joined with small clamps A-10 in order to form only one model. In Fig. 6 has been shown a three span portal frame, the shape frequently used in factory building, the model having been composed of the complete central part with the two aisles attached by small clamps. At the left of Fig. 6 the supports of the columns have been supposed hinged and the photograph shows the "Continostat" holding the model in the swivel heads of the A-2 rods with the foot of the third column shifted to the right by any not too large distance $s/2$, forming that way the influence line of the horizontal thrust at the foot of the third column. By pulling a small lever at the swivel head of the A-2 rod those heads cannot gyrate and will produce automatically the same influence lines for fixed supports as indicated in dotted lines to the right of Fig. 6.

Plastic models are especially convenient for quick estimating work; with reasonable care the results with the same will stay within 5% of those obtained by exact analysis.

#### 4. STEEL SPLINE MODELS.

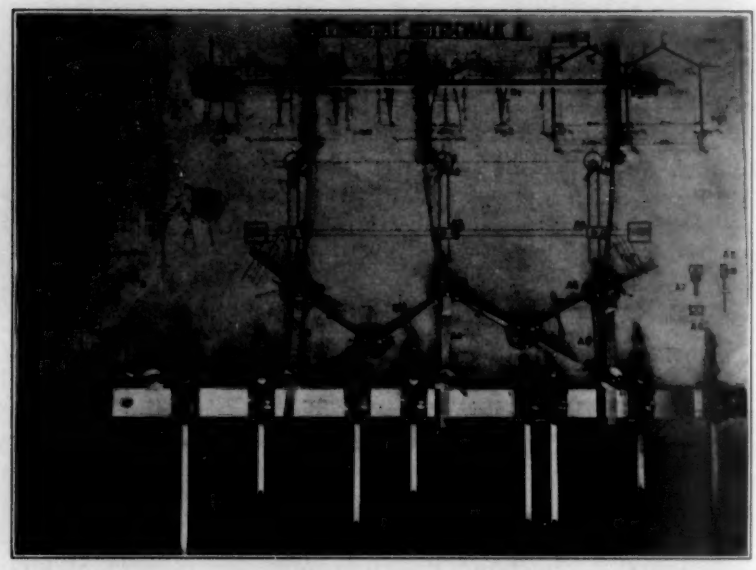
Steel splines do not lend themselves to curving or breaking, they admit however very large deformations, returning with great force to their original shape however long time they may have been bent; consequently they should be used for very accurate work and especially where models may be composed of straight splines, or as indicated in the following chapter.

As an example Fig. 7 shows the statical calculation of an airship shed. The model has been composed of short, straight and strong splines joined with A-6 ring clamps. The model is being held upside down, at the column feet by means of the A-2 rods in the sliding rod of the "Continostat" and at the heads of the columns by the A-4 gooseneck rods, which on their part slide and gyrate in the A-1 devices attached to the rods of "Continostat" itself. The interior A-4 rod has been fixed, the two exterior ones may swing freely. The photograph Fig. 7 shows how the thrust at the interior column is being obtained by shifting the foot of the same any distance $s/2$ towards the column to the left, whereupon the frictionless sliding rule swings automatically to the right until the elastic equilibrium of the model has been regained, that is to say,

until the model has bent into the exact shape of the influence line for the horizontal thrust at the foot of the interior column.

In the same photograph Fig. 7 have been marked to the left in small scale the influence lines of bending moments at corners obtained by gyrating one leg of the ring clamps with respect to the others by $2 \times$ "½" = "1." No part of the model should touch the paper until deformation has taken

FIG. 7.



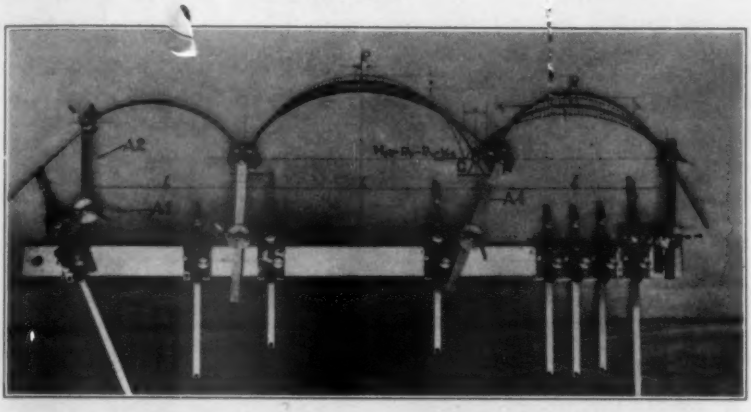
place; plastic models might be lifted a bit from the table and stay without rubbing on paper, whilst when using ring clamps the small frictionless rolls may be slipped underneath the model at strategical places, to keept the model from touching the table.

### 5. ARCHES.

Frequently it is possible to form arches, holding under stress straight steel splines by approaching two points of the same, until rise and shape of arch desired have been obtained. The continuous three span arch supported at different levels Fig. 8 has been formed that way. Angles between arches at interior supports have been fixed by means

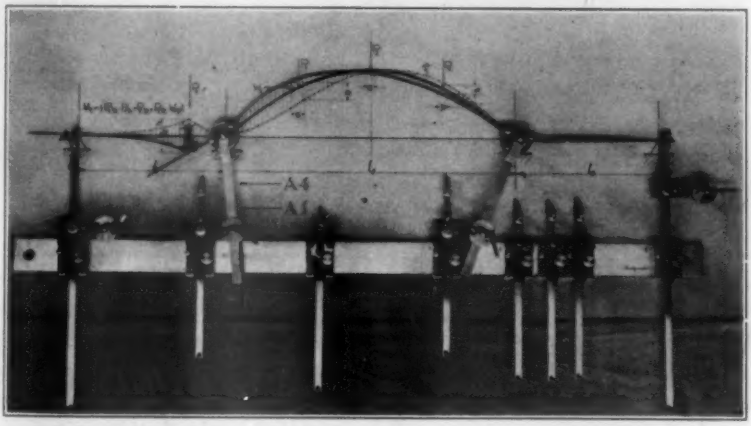
of the ring clamps, which however may gyrate freely around their axis, held in A-4 rods. The photograph shows the rod

FIG. 8.



holding third support *C* shifted to the right in order to obtain immediately the horizontal thrust at that support.

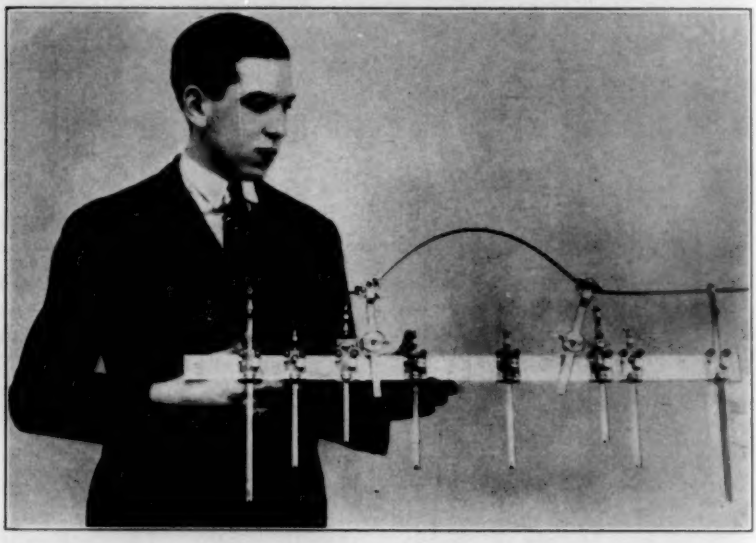
FIG. 9.



Similarly in Fig. 9 an archbridge with two straight end-spans has been reproduced with straight steel splines. By inserting the No. 2 clamp of the "Continostat" at any section, e.g. in the left span as shown, the influence line of

the bending moment at that section is obtained. Fig. 10 again shows the model of the same structure, however with the second support from left shifted a small distance to the right, obtaining that way the influence line of horizontal thrust at the second support; note how the model is being

FIG. 10.



held freely in the "Continostat," so that deformations may take place accurately without danger of rubbing on drafting table or any other exterior hindrance.

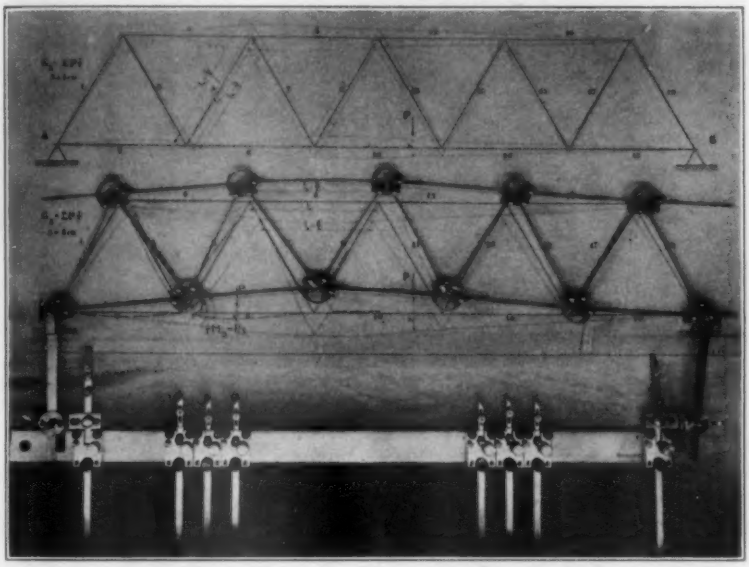
### 6. LATTICED TRUSSES.

The "Continostat-A" and especially the A-6 ring clamps open up new fields which do not lend themselves to analytical investigation; as an example, secondary stresses may be calculated due to deviation of shopwork from theoretical assumptions e.g. when using riveted, or welded, joints in latticed trusswork, where for statical calculations hinges without friction are supposed.

Fig. 11 shows a plain truss composed of steel splines joined by A-6 clamps, the holders of which are fixed to the rings. By spacing farther apart the second and third clamp

on the upper chord, the model is forced into the shape of the real influence line of compression in second panel of the upper chord, for rigid joints. Now we may go along loosening two of the legs of each ring clamp whereupon the diagonals of the truss straighten themselves forcefully and eventually the model forms the influence line for hinged joints. The difference from the influence line obtained before for rigid joints show automatically the secondary stresses due to the same.

FIG. 11.



Secondary bending moments at rigid joints are automatically shown by gyrating the one leg of ring clamp where moment is wanted with respect to the others. To the left of the lower chord in Fig. 12 the influence line of secondary bending moments in chord has been obtained that way as shown in dotted line.

The simpleness and efficiency of this method may be more clearly illustrated in Fig. 12, showing the cross section through a three chord truss. By inserting the No. 2 clamp of the "Constinostat" in the center of the lower crossbeam we get the heavy influence line of bending moments there shown in

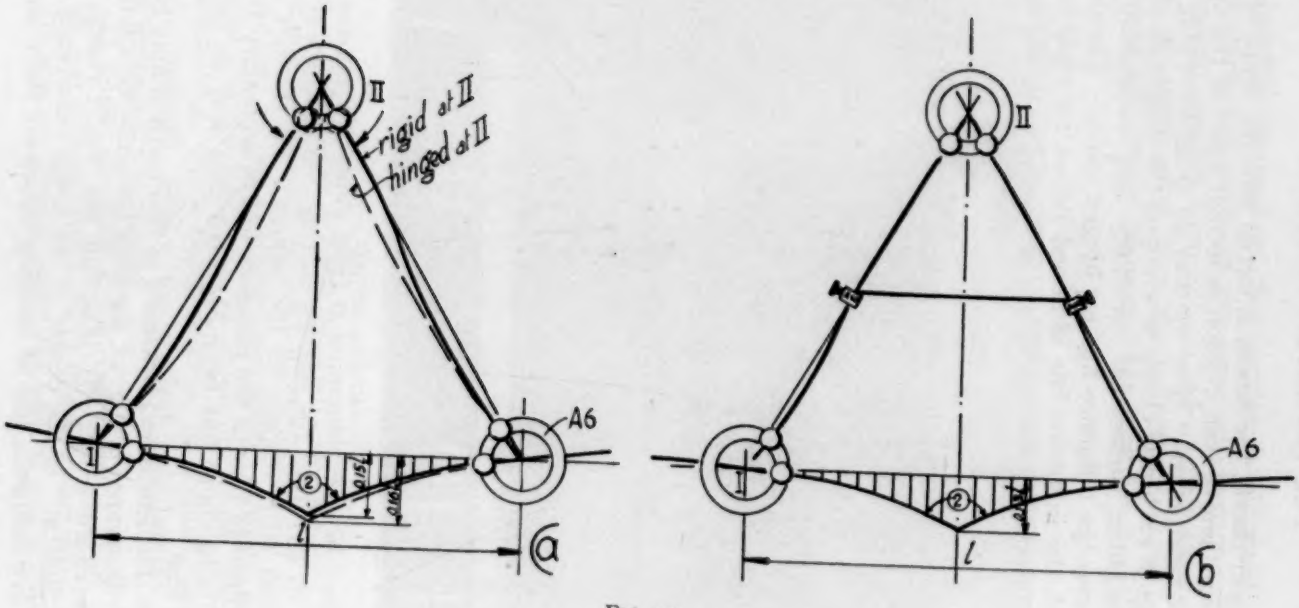
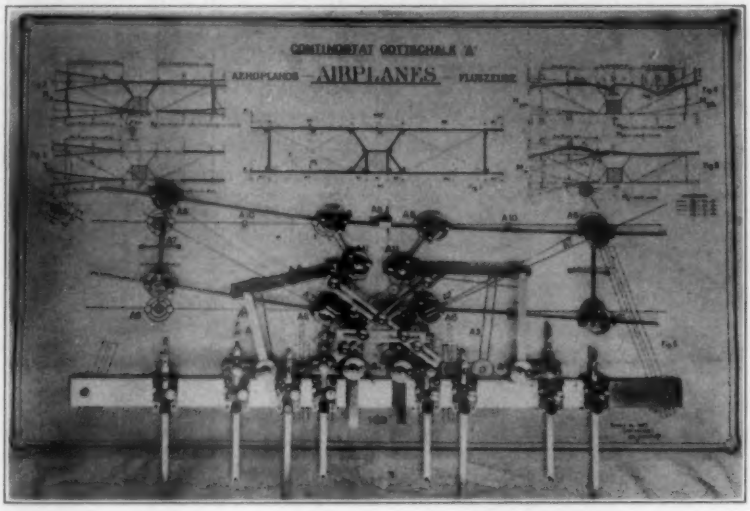



FIG. 12.

Fig. 12 to the left when joint at II on top is rigid. If that joint however is hinged we loosen one of the legs there, whereupon the model will snap forcefully into the shape indicated in fine dotted line, increasing the ordinate in center of crossbeam from $0.15l$ to $0.16l$. If therefore a load $W$ were distributed over the entire crossbeam the bending moment produced in center of same would be, when all three joints

FIG. 13.




are fixed, $M = (2/3 \times 0.15l - 1/24l)W = 0.058lW$ and when the joint on top is hinged

$$M = (2/3 \times 0.16l - 1/24l)W = 0.065lW;$$

that means an increase of 11 per cent. Bracing the triangular frame with a strut at half height the influence line will be as shown in Fig. 12*b*, reducing ordinate in center to $0.13l$; in this case however the loosening of the A-6 clamp on top viz. introducing a hinged joint on top will not alter appreciably the result.

### 7. COMPOUND STRUCTURES.

The methods explained in this article have made it possible to calculate many statical problems which before had to be

solved by empirical formulas, e.g. in shipbuilding, in parts of engines, etc. Fig. 13 shows an application for calculating stresses in airplanes. The four hinges forming the supports of the statical system are so close together that small difference there may multiply and produce relatively large errors on the outside. To prevent that, the mutual position of those supports is being especially fixed by means of the stabilizer A-12. The photograph shows how the stress in one of the diagonal wires is being obtained by lengthening or shortening of the respective spline, which is inserted on top of two A-6 clamps by means of the tension rod inserts A-7.

November 9, 1928.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### UNIDIRECTIONAL RADIO BEACON FOR AIRCRAFT.

DURING the development by the bureau of a directional beacon for guiding aircraft, it appeared that the usefulness of the beacon could be increased by making the radiated field unidirectional. This was accomplished by the combined use of a vertical antenna with the two crossed-coil antennas utilizing the directive and non-directive fields simultaneously, with the proper phase and amplitude relations between them to secure unidirectional transmission.

The system is explained in a paper "Unidirectional Radio Beacon for Aircraft" by E. Z. Stowell in the Bureau of Standards Journal of Research for December, 1928, Research Paper No. 35. Reprint copies of this paper may be obtained for ten cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

### A LABORATORY INTERNAL MIXER FOR RUBBER.

A SMALL internal mixer for rubber has been installed recently. Various extraction and drying operations have been performed with the use of the mixer, in addition to the compounding of rubber for which it was designed.

The mixer consists essentially of shaped rotors moving in opposite directions at different speeds in a closed chamber. Temperature control is effected by a jacket for steam and water at the bottom of the chamber. The working capacity of the mixer is 500 to 2,500 grams of rubber. The machine is driven by a motor with variable speed control.

A variety of stocks has been successfully compounded with the mixer. Those containing large proportions of graphite have been mixed by the machine with greater facility, ease, and accuracy than on the usual laboratory roll mill. Sulphur, accelerators, and even ultra-accelerators are

* Communicated by the Director.

usually incorporated in batches in the mixer. Temperature control is not difficult, as in case of factory size internal mixers on account of the relatively larger surface per unit volume of rubber.

No critical study has, as yet, been made of the performance of the laboratory internal mixer or of the properties of rubber compounded in it. However, such an investigation is contemplated.

The mixer has been used as an extraction apparatus by mascerating rubber or other gums with successive portions of solvent in the closed mixing chamber. Since a large and continually renewed surface of the gum is presented to the action of the solvent, the extraction process is relatively rapid and efficient. Furthermore it is possible to work with very soft and tacky gums that would be difficult to handle with usual laboratory extraction equipment. The machine has also been used to make special rubber cements having a wide range of consistencies.

The internal mixer has also been found convenient and effective for the drying of rubber. During this operation an inert gas, such as carbon dioxide, is usually circulated through the mixing chamber to carry out vapors and to avoid oxidation by air. The machine is designed to permit its operation with the chamber evacuated, but this feature has not yet been tested.

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## COLLOIDAL CONTENT OF CHINA CLAYS.

INCLUDED in the program of the china clay investigation is a study of grain size distribution. While this has been carried out by the sedimentation process and application of Stokes' law down to a particle size diameter of 1.7 microns, the data indicated that from 35 to 60 per cent. of the total clay had a grain size of less than 1.7 microns. Since this large quantity of finely divided material undoubtedly has a pronounced effect upon the properties of the clay, it seemed desirable to make a further classification as regards size.

After reviewing the literature and studying the methods of various investigators, it was decided that centrifuging was the best way to effect the separation. Hand and motor driven

centrifuges were tried, but the speed was insufficient and a Sharples laboratory super-centrifuge was obtained. It was found that for a suspension of 1.6 specific gravity and a range of flow of 20 liters per hour, the centrifuge would throw out of suspension all particles greater than one micron in diameter when rotating at 12,000 r.p.m.

The particle size was checked with a microscope using a 12.5 micrometer eyepiece and an oil immersion objective. The second separation consisted in taking the suspension from the first and centrifuging it at a speed of 18,000 r.p.m. and a rate of flow of about 8 liters per hour. The material remaining in suspension after the second separation was removed either by centrifuging at 40,000 r.p.m. and a very slow rate of flow, or running through a set of Pasteur-Chamberland filters. The ultra filters have a slight advantage over the centrifuge in that they remove every particle of suspended matter while the centrifuge leaves a trace in suspension.

The Bureau of Chemistry and Soils has done considerable work on the estimation of colloidal material by obtaining the adsorption of water or other liquids, by the clay and by a sample of the total colloid. The adsorption in grams per gram of the total clay divided by the corresponding value for the total colloid gives the percentage of colloid. This method will be used to estimate the total colloid present in the clays. The figure obtained should check roughly the amount indicated in the earlier work as being under 1.7 microns. Then to go farther, it is desired to compare the quantities of material obtained from the second and final extractions of any one clay with like quantities from any other clay. If the same volume and the same concentration of suspension are used for the various clays, then under similar conditions of centrifuging, the actual amounts of material thrown out at any one speed should be relative and comparable. The separated material can be carefully removed, dried, and weighed.

Thus far data have been collected on a few clays only, but it is expected that considerable difference between one clay and another will be shown in the quantities of these fractions.

## ABSORPTION OF CLAY BRICK.

IN connection with an investigation, sponsored by the American Face Brick Association, of the factors controlling the moisture transmission of brick masonry, a study has been made of the absorption properties of nine different types of clay brick. All bricks of one type were made at the same plant and differed from those of other types in the clay used and in certain details of manufacture. Among the nine different types investigated were included bricks made by the stiff mud and dry press processes. The samples of each type used in the absorption tests were selected to give as wide a range in the properties as could be obtained from several hundred marketable products. Those selected were free from large cracks or laminations. The absorption tests included measurements of the water absorption of brick by total immersion at room temperature, total immersion in boiling water for 7 hours, and partial immersion at room temperature for several periods. The absorption by partial immersion was determined by noting the increase in weight of an initially dry brick when one surface was kept in contact with water and the other surfaces were surrounded by an atmosphere saturated with water vapor.

The results of the tests indicated that the relations between the amounts of water absorbed by total immersion at normal room temperature and by boiling were given closely by the empirical equation

$$Y = KX^3 \qquad \text{or} \qquad Y = K\left(\frac{Y}{Y+Z}\right)^3,$$

where $Y$ = volume of water absorbed per unit of bulk volume of brick after total immersion at room temperature. (Taken at a period when the gain in the weight of the brick was less than 1 gm. per 24 hours.)

$Y + Z$ = volume of water absorbed per unit of bulk volume of brick after 7 hours total immersion in boiling water.

$K$ = a constant for one make of brick.

$X = \dfrac{Y}{Y+Z}$ = ratio of absorption by cold immersion to absorption by boiling.

The absorption constant $K$ was different for different types of brick but was essentially constant for any one make of brick. Since the values of $K$ were independent of the degree of burning and were constant for brick made from the same clay by the same manufacturing process, there seems to exist the possibility that clays may be classified in accordance with these values, though it has not been determined definitely to what extent (if any) they are affected by the manufacturing process.

With any one type of brick the values of the ratio $X$ decreased with a decrease in the apparent porosity of the brick, but there was not a close relation between these two values with brick of different type. Since the quantity $Z$ is that part of the total open pore space which can be entered during the cold immersion test, it may be termed the residual porosity. By combining the equation $Y = KX^3$ and $X = \frac{Y}{Y+Z}$ and solving for $Z$, it can be deducted mathematically that $Z$ is a maximum when $X = \frac{2}{3}$. This relation was borne out by the results of the tests the values of the residual porosity $Z$ being greatest with any one type of brick when the value of the ratio $X$ was about 0.67.

When a definite surface area of a brick is in contact with water at normal room temperature, the rate of gain in weight of the brick because of water absorbed by capillarity has been in all cases such that $\frac{d}{dT}\left(\frac{W}{T^{1/3}}\right) =$ a constant, $B$. $W$ is the gain in weight of the brick at any definite time interval $T$. In all cases wherein the rate of absorption was slow, thus making possible an error due to evaporation, the tests were conducted in an atmosphere saturated with moisture.

Performing the indicated operation $\frac{d}{dT}\left(\frac{W}{T^{1/3}}\right)$, there results the equation, $\frac{dW}{dT} - \frac{W}{3T} = BT^{1/3}$, which when integrated, gives the equation, $C = \frac{W}{T^{1/3}} - BT$, where $C$ is an integration constant. This latter equation has been applied to each of the nine types of brick studied. The quantity $\frac{W}{T^{1/3}} - BT$,

has been found to be constant within the limits of experimental error for any one single individual brick among all of the nine types of brick studied.

Among brick of any one type, the magnitude of $C$ is directly proportional to $Y$, the apparent maximum volume of water absorbed at room temperature per unit bulk volume of brick. This relation is expressed by equation (1), $C = K'Y^3$ or $Y = \left(\frac{C}{K'}\right)^{1/3}$. But since (2) $Y = KX^3$, the value for $Y$ in equation (1) may be substituted for $Y$ in (2) and there results equation (3) $\left(\frac{C}{K'}\right)^{1/3} = KX^3$. Equation (3) contains every absorption property characteristic of any single brick selected from any of the nine manufacturers' marketable brick.

It is expected that noticeable deviations from these relationships will obtain in the case of any brick that is either distinctly under-burned or over-burned.

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### DIATOMACEOUS SILICA AS ADMIXTURE IN CONCRETE.

A STUDY of the representative diatomaceous silicas commercially produced in the United States for use as admixtures in concrete is now being made at the bureau; eleven representative samples having been obtained from nine producers. The purpose of the study is the development of Federal specifications for this material.

The petrographic analysis, fineness through the No. 200 sieve, and weight per cubic foot, have been determined. The material runs from a minimum of approximately 70 per cent. diatomaceous silica mixed with quartz and clay to practically pure diatomaceous silica. All samples are finely divided from 86.2 to 99.5 per cent. passing a No. 200 sieve.

As usual, the determination of the weight per cubic foot introduced difficulties, the weight of any one material varying according to the method whereby it is placed in the measure.

A ⅓d cubic foot aluminum measure, 8 inches in diameter, was made expressly for the measurement of the weight per cubic foot. The dried diatomaceous silica was always screened through a sieve into the measure. It was found that

a $\frac{1}{8}$ or $\frac{1}{4}$ inch opening gave the same results. The $\frac{1}{16}$ inch opening was too small, the material caking and blocking the sieve opening.

Hand sieving required such considerable time that motor driven apparatus was built. A 1/100 H.P. motor drives through worm and wheel a vertical shaft, at the end of which another horizontal shaft forms a *T*. The horizontal shaft rotates over the screen surface and about $\frac{1}{16}$ inch above it. If the distance above the screen is too great the material will cake and if too close it will touch the screen at some spot, cause movement of the screen and thus shake the material through, with a resultant change in unit weight. The weight per cubic foot will vary with the speed of the rod, and this speed will vary with the amount of material on the sieve. For this reason the diatomaceous silica is slowly added to the screen from a scoop, so that never more than $\frac{1}{2}$ inch of the material is on the screen. The mean velocity of the rod is about 120 r.p.m.

The weights per cubic foot of the materials varied from 7.5 to 34.7 pounds. Only one specimen, however, weighed more than 16.2 pounds per cubic foot, six of the specimens varying from 14.3 to 16.2 pounds per cubic foot.

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## PANEL TESTS OF LIME PLASTER.

IN March, 1922, a series of panels of lime plaster was erected, using several types of limes and intentionally including in the finish coat various impurities. The panels were allowed to age under ordinary laboratory conditions and at the end of a year an inspection was made to determine the effect of the various impurities. The results of the first inspection were published by Emley and Berger in the Journal of the American Ceramic Society, Vol. 6, No. 9; September, 1923, under the title "Panel Tests of Lime Plaster."

A recent inspection, made nearly seven years after the panels were erected, shows that while the majority of the panels are apparently in the same condition as in 1923, certain ones have developed defects not noticeable at that time.

In the construction of the panels four sets of duplicates were made containing, respectively, hydrated lime, lime plus coarse impurity, lime plus medium impurity, and lime plus fine impurity.

For convenience in reference, the 1923 report on the panels which have undergone change since then is given below, together with comments on their condition in December, 1928.

Hydrate No. 5 plus iron carbonate.

(1923) The hydrate itself shows a few pops and cracks. The additions of iron carbonate seem to have no effect.

(1928) Decided map cracking has developed on the panels containing lime without impurity. Numerous cracks and pops have occurred on the panels containing coarse and medium impurity; some have occurred on the panels containing fine impurity.

Hydrate No. 6 plus quicklime.

(1923) The fine quicklime shows no noticeable effect; the medium shows a few additional pops, and the popping of the coarse particles is quite apparent.

(1928) Numerous pops have developed on the panels containing fine quicklime.

Hydrate No. 10 plus lime burned during hydration.

(1923) The coarse particles caused a few pops; with the medium size the pops are almost negligible; and the fine material caused no popping.

(1928) Considerable cracking appears in the panels containing medium and fine burned lime.

Hydrate No. 11 plus tannic acid (fine).

(1923) The surface is badly checked and discolored.

(1928) Several large pops are noticeable.

The results of this later inspection indicate that while in the majority of cases defects which develop in lime plaster are noticeable at the end of a year, certain impurities may cause defects which are only apparent after several years' aging.

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## FIRE RESISTANCE OF HOLLOW LOAD-BEARING WALL TILE.

THE results of comprehensive tests to determine the fire resistance value of hollow clay wall tile conducted in cooperation with the Hollow Building Tile Association are

reported in the January number of the Bureau of Standards Journal of Research. (Research Paper No. 37, 334 pages. Reprints obtainable from Superintendent of Documents at 75 cents per copy.)

While hollow clay tile has been used in this country for about 50 years in floor arches, partitions and as protection for structural members, only during the past 20 years has it been extensively applied for load-bearing purposes in walls. The safe and economical use of this material as of other masonry materials, requires knowledge of its strength and fire resistance under conditions imposed by severe fires. Fire resistance of walls is rated mainly on ability to keep the temperatures of the side away from the fire to a point where they will not ignite combustible materials in contact with the wall. Ability to carry load throughout the fire and to withstand the impact from hose streams are also necessary conditions. The amount of damage incurred and methods of making repairs are also of interest.

The work reported in the paper consists in the main of three series of fire tests of wall construction built of tile of representative designs and clay materials. The first tests were made on wall sections 1 foot wide and 6 feet high that were subjected to fire on one side while under working load, the main object of the tests being to determine how the fire exposure affects the individual tile units. This was found to vary with the type of clay used, hardness of burning and design of the unit, from minor cracking of a few of the units in the specimen, to failure under load a little after 2 hours.

The second group of tests was with wall specimens 4 feet wide and 4 feet high tested exposed to fire on one side, under load or restrained within the containing frames, and was made to study the effect of changes in design of the unit, and in the constitutents and preparation of the clay.

Addition of ground burnt clay (grog) to the raw clay in amounts up to 2 per cent. was found to be without effect, but higher percentages increased the fire damage, apparently because of initial shrinkage cracks radiating from the grog particles. Additions of sawdust to the raw clay in amounts up to 15 per cent. by volume decreased the tendency to cracking when exposed to fire without seriously decreasing the

normal strength of the tile. Fine grinding and greater amount of pugging of the raw clay increased the strength of the tile and consequently its load-carrying ability when exposed to fire.

Of modifications in the design of the unit, one with double outside shells improved the fire resistance for all but very dense tile in confining the cracking mainly to an outer thin shell. Increased shell thickness was also found to decrease the fire effects, as also fillets of up to $\frac{1}{4}$ inch radius at the junctions of shells and webs.

The final series consisted of 167 fire endurance tests and four fire and water tests of typical wall constructions, 71 of which were made with walls between 10 and 11 feet high and 8 to 16 feet wide. The thickness ranged from 8 to 16 inches, and plaster, stucco, or brick facing was applied on a number of the walls. The walls were subjected to constant applied loads of 70 to 120 lbs./in.$^2$ during the fire test, were restrained within the containing frames, or were tested unrestrained, the latter condition being representative of walls in low buildings or the upper story walls of higher buildings. The results are summarized as fire resistance periods, which are determined by the time the walls sustained load under fire exposure and prevented the average temperature rise on the unexposed side from exceeding 139° C. (250° F.), or the maximum rise at any point where temperature measurements are taken from exceeding 180.6° C. (325° F.). Freedom from cracks or openings large enough to transmit flame or ignite combustible materials is also required both in fire endurance tests and fire and water tests.

The final grouping of test results is in three classes, determined by the design of the tile. Fire resistance periods are given for 8, 12, and 16 inch walls in each class, the values varying with the thickness and design from 1 to 11 hours for unplastered walls and from 4 to 15 hours for walls plastered on both sides. Periods are also given for walls assumed to have combustible members projecting into them 4 inches from the unexposed side, this being determined by the time required for temperatures high enough to ignite wood to obtain at the given depth in the wall. Fire resistance periods for this condition ranged from one hour with 8-inch unplastered walls to 10 hours with 16-inch plastered walls built of tile of the designs giving the highest results.

Gypsum and portland cement plasters applied on one or both sides of the wall constructions not only increased their fire resistance periods but that on the side exposed to fire also appreciably decreased the fire effects on individual units and the construction generally. Where applied on split furring tile, plaster was found to prevent all fire damage to the load-bearing tile in fire tests lasting as long as six hours.

**Tests for Hydrocyanic Acid.** G. C. SHERRARD of the U. S. Public Health Service (*Pub. Health Rep.*, 1928, *43*, 1016–1022) has studied methods for the detection of gaseous hydrocyanic acid (prussic acid) in the air.

He considers the benzidine-cupric acetate test to be too rapid and too sensitive for practical purposes in fumigation. In this test, a test paper containing benzidine acetate and cupric acetate yields a blue color with hydrocyanic acid; a pale blue results in 10 seconds if 2.8 grams of hydrocyanic acid be present in 1,000 cubic feet of air. Chlorine and the oxides of nitrogen also respond to this test.

For the methyl orange-mercuric chloride test, two solutions are prepared; one contains 1.25 grams of mercuric chloride in 250 cc. of distilled water; the other contains 0.60 gram of methyl orange in 250 cc. of distilled water. The reagent is obtained by mixture of 10 volumes of the mercuric chloride solution, 5 volumes of the methyl orange solution, and 1 volume of glycerol. Test papers are prepared from this reagent, and retain their reactivity for a period of 14 to 30 days if kept in a dark, tightly stoppered container. They are most effective when their moisture content lies between 7 and 8 per cent. They react with hydrocyanic acid to produce a pink or red color. The color depends upon the concentration of the hydrocyanic acid, and the time of exposure. Thus a faint pink color is produced by 1.67 grams of hydrocyanic acid per 1,000 cubic feet of air acting for 2 minutes, by 3.35 grams per 1,000 cubic feet acting for 1.5 minutes, or by 6.7 grams per 1,000 cubic feet acting for 1 minute. Chloropicrin, in a concentration of 0.02 per cent. by weight has no action in this test in a period of 6 minutes. The test paper may be introduced into fumigated holds of ships by means of a clip and string.

Albino rats may be used to detect the presence of hydrocyanic acid. Thus, 3.35 grams of hydrocyanic acid per 1,000 cubic feet of air is the minimum lethal dose in a gas-tight compartment in an exposure of 12 hours.

The sense of smell reveals the presence of as little as 0.25 cc. of liquid hydrocyanic acid diffused in 1,000 cubic feet of air.

J. S. H.

## NOTES FROM THE U. S. BUREAU OF MINES.*

### BENTONITE, A MINERAL OF MANY POSSIBILITIES.

ONE of the oddest and least known mineral substances is bentonite. Certain bentonites have such strong affinity for water that they are capable of absorbing more than ten times their volumes of water. Owing to its peculiar physical properties bentonite has been suggested as a component material in the manufacture of a great variety of commodities as diversified as paper, rubber, putty, phonograph records, pencil leads and soaps. On the other hand, because of its tendency to swell greatly when wet, underground deposits of bentonite have caused great difficulties in the drilling of oil wells, it frequently becoming necessary to take special steps to combat the nuisance.

The properties, mining, preparation and utilization of bentonite have formed the subject of an investigation recently conducted under a coöperative agreement between the United States Bureau of Mines and the Mackay School of Mines, University of Nevada. A large number of samples of bentonites from many sections of the United States were studied in the course of this investigation.

Bentonite is a rock that contains 75 per cent. or more of the crystalline claylike minerals montmorillonite or beidellite.

Investigators have recognized the occurrence of a peculiar claylike substance which, when wet with water, resembled soft soap and was called "mineral soap" or "soap clay" for a long time. Early reports show that such material had long ago been used at the Hudson Bay posts in Canada for washing blankets.

The first shipments for commercial purposes were made in 1888 by William Taylor of Rock Creek, Wyo., after whom the material was called "taylorite." In 1898, however, it was learned that the name taylorite had already been used as a mineral name for potassium ammonium sulphate, so that this

* Published by permission of the Director, United States Bureau of Mines.

substance was then designated as bentonite from its occurrence in the Fort Benton formation of the Rock Creek district.

At the time considerable interest in bentonite was aroused, but it quickly subsided and the price of $25 per ton was soon reduced to $5 per ton. Within the last few years the interest in bentonite has revived, resulting in investigations that have developed industrial processes and products in which bentonite apparently has an important part. The prices today at western points for the finely pulverized material approaches the first quoted price.

Of the many uses suggested only a few have been tested, and investigators have not worked out the properties of bentonite that determine its usefulness or made tests to determine what type of material is best suited to the different uses.

Bentonite deposits occur in beds from a few inches to many feet thick, mainly in the Tertiary but to some extent in the Paleozoic and Mesozoic rocks in many parts of the United States and Canada, and deposits have been reported from Mexico, China, and France. Most bentonite deposits are the result of devitrification and partial decomposition of glossy volcanic ash.

Bentonite outcrops are unique and striking. As little vegetation will grow on them, they are barren, and because of the peculiar physical properties of bentonite these weathered outcrops often present a crinkled coral-like appearance. If the internal portion of bentonite is dry, it may finally absorb water and swell greatly, producing cracks in the surface layer, which has meanwhile become more or less dry. After a rain many bentonite outcrops are covered with a thick mass of slippery jelly, but in dry weather the surface may be dry and fluffy or may have a peculiar granular appearance.

The bentonite of Wyoming is usually considered a standard type in studying other so-called bentonites. One of the important producers of the material has deposits at Medicine Bow and a grinding plant at Cheyenne. Another important producer in Wyoming has a mine at Clay Spur, near Newcastle. A large new deposit of bentonite has recently been reported in Johnson County.

The largest known California bentonite deposits occur in

the arid desert region along the Amargosa River in Inyo County. A material closely resembling Wyoming bentonite occurs at Belle Fourche, South Dakota. On claims owned by one company at this place, there is estimated to be millions of tons of high-grade bentonite. Other deposits are located in Nevada, New Mexico, Idaho, Tennessee, Kentucky, Alabama, and other states.

Nearly all deposits of bentonite contain gritty or sandy inclusions, which are considered impurities and must be removed before marketing. Pulverized bentonite is fine grained and commonly light colored, ranging from cream to olive green; but it may be pink, dark brown, or even black, the color usually but not always becoming darker on wetting. When fired the color is white, buff, or brown. When cut the fresh material usually has a waxy luster which may become dull or powdery on drying. Some varieties may be cut into thin shavings.

Prospectors or others who become interested in the production of bentonite should make a careful investigation of the commercial possibilities of the deposit in question before investing heavily. Such a study should include the possibility of marketing the product, the specifications demanded, the price obtainable, the cost of mining, treating, and shipping to market, the size of the deposit, and the nature of the crude bentonite. One should also realize that most consumers desire a homogeneous product that will remain uniform over a period of years and that deposits containing bentonite which will do this are not common; that most crude bentonites contain appreciable quantities of objectional impurities such as sand, gypsum, carbonaceous matter, or soluble salts that must be removed at considerable expense by washing; and that the purified bentonites from different deposits and even from different levels or parts of the same deposit may have very different properties, such as variation in color, colloid content, and ease of hydration. In general, consumers want a clean, homogeneous, finely divided substance.

Purified, ground alkali bentonites should make admirable fillers, binders or plastics in the manufacture of numerous industrial materials due to its general characteristics, such as extreme state of fine division, property of remaining in

suspension, plasticity, and high absorbent power. Thus bentonite should be useful in the manufacture of paper, linoleum, curtain cloth, cordage, rubber, ceramics, Portland cement, lubricating greases, putty, phonograph records, crayons, plasters, paste, glue, shoe and stove polishes and numerous other materials.

The characteristics of bentonite as an adsorbent, emulsifier or peptizer, should make it available in the manufacture of soaps and detergents, horticultural sprays, animal dips, insecticides, fungicides, paints, inks, water-proofing plasters and dynamite; in the de-inking of printed papers, the refining of oils and fats and in the removal of water from petroleum. As a chemical reagent bentonite should be of value as a water softener, as an aid to soil fertility and in the treatment of molasses. It is also suggested for use as a medical dressing in certain drugs and in beauty clays.

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### COAL MINE DRAINAGE MAY SOMETIMES AID IN PURIFYING STREAMS.

IT is the common opinion that with rare exceptions all active coal mines produce drainage which contains acid, and that the discharge of that drainage into natural streams contributes to pollution from the standpoint of the use of the water for domestic and industrial purposes; as well as a habitat for aquatic life. While this is true in varying degrees for the majority of coal mines, it has been disclosed in a study of coal mine drainage that is being made by the Pittsburgh Experiment Station of the Bureau of Mines that the water from a considerable number of mines in the Thick Freeport Bed in the vicinity of Pittsburgh is rather strongly alkaline, and instead of contributing to the pollution of the streams into which the mine water drains, it is actually an agent which aids in neutralizing acid that may already be present, or which may enter later from other sources. The absence of acid in the drainage from these mines is apparently due to the fact that the water which enters at the depth of the workings contains more than enough alkaline compounds in solution to neutralize all the acid with which it comes in contact in the mine. In some instances this has been substantiated by

finding both acid water in one section of the mine and alkaline in the other, whereas the combined effluent stream of water was alkaline.

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### A STUDY OF THE FORMS IN WHICH LEAD IS NOW BEING LOST IN SMELTER SLAGS.

As the studies made by the United States Bureau of Mines at its North Central Experiment Station at Minneapolis have resulted in furnishing a large amount of data which have been of assistance to iron blast furnace operators in understanding the chemical phenomena of the iron blast furnace and the circumstances which govern the successful operations of such a furnace, the Bureau decided, in connection with its work on increasing the efficiency of metallurgical practices, to apply similar studies to the operations of the lead blast furnace. This study was assigned to the Intermountain Experiment Station at Salt Lake City, Utah, and is now being conducted in coöperation with one of the local smelting companies.

In connection with this work the following studies have been made:

(*a*) Location and chemical composition of the accretions in lead blast furnaces.

(*b*) The rate of charge movement in the furnace.

(*c*) The liberation of sulphur from blast furnace charges in the form of $SO_3$ and $SO_2$.

(*d*) The zone of maximum reduction of lead.

(*e*) The relation of temperature, CO concentration and slag composition to reduction of lead.

Along with the other studies that are being made, particular attention is being given to accretions. Chemical analyses are made of them. From the difference in composition and texture of the various zones of the samples, an attempt is being made to study the history of the formation of the accretions and from the data obtained, to devise a method to prevent their occurrence.

Interesting data are also being obtained in connection with the studies which are being made on the composition of lead blast furnace slag. The results of the investigation to date show in general that the lead blast furnace is much less

uniform in operating behavior than is the iron blast furnace. The temperature and composition of the gases obtaining at the various tuyeres vary both from each other and at various stages in the cycle of operation. These fluctuations influence profoundly the composition of the slag, the loss of unreduced lead, and the rate of smelting at the various tuyeres.

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### BARIUM OXIDE AS A BLAST-FURNACE FLUX.

A comparatively expensive flux could be used in blast-furnace practice provided small amounts of it would produce a substantial increase in the desulphurizing action of the slag without making the slag more viscous. Such a flux would be particularly beneficial to operators using coke containing more than 1 per cent. sulphur, because as the sulphur in the coke exceeds this amount changes in operation necessary to keep the sulphur in the metal within specifications become increasingly expensive.

Results from laboratory tests made at the North Central Experiment Station of the United States Bureau of Mines, Minneapolis, Minn., indicate that slags containing barium oxide do not desulphurize more readily than normal slag containing calcium and magnesium oxides. A comparison of the desulphurizing action of slags was made by holding contiguous layers of the molten slags and high-sulphur metal in contact at temperatures from 1,400 to 1,600° C. Small streams of metal were also passed through layers of the various slags to assimilate the passage of globules of metal through the slag bath in the crucible of the blast furnace. Due to the high molecular weight of barium oxide it is only equivalent to about one-third its weight of calcium oxide as a base for fluxing silica. A replacement of about one-fourth the calcium oxide with barium oxide increased the rate of sulphur elimination. However, the cost of barium oxide necessary to replace this fraction of the calcium oxide in blast-furnace slag would be prohibitive.

# THE FRANKLIN INSTITUTE.

## ANNUAL MEETING, WEDNESDAY, JANUARY 16, 1929.

The annual meeting of The Franklin Institute was called to order at eight-thirty p.m. by the Acting President, Mr. Henry Howson.

The Secretary reported that the minutes of the December meeting of the Institute had been published in full in the January number of the Journal of the Institute. He therefore moved that the minutes be approved as printed. The motion was seconded and adopted. The minutes were then declared approved.

The Secretary stated that the detailed reports of the various committees of the Institute and of the Board of Managers would be published in full in the Year Book, for those interested in the details of the administration of the Institute. To read these at this time would require far too much time.

The Secretary then read, on behalf of the Acting President, his report as President, which also will be published in full in the Year Book. He supplemented the statement of the Acting President by the announcement that the Mayor of Philadelphia intended to celebrate Franklin's birthday by introducing into the City Council the Ordinance authorizing the use of the plot of ground bounded by Twentieth, Winter, Twenty-first and Race Streets, for the new Franklin Institute and Benjamin Franklin Memorial.

The report of the Tellers of the election, Drs. Henry Leffmann, Wilbur M. Stine, and Mr. W. N. Jennings, was then read by the Secretary. It showed that the following gentlemen had been elected to the offices indicated:

For President (to serve one year), Nathan Hayward.

Vice-President (to serve three years), C. C. Tutwiler.

Treasurer (to serve one year) Benjamin Franklin.

Managers (to serve three years), James Barnes, G. H. Benzon, Jr., G. H. Clamer, Theobald F. Clark, A. W. Goodspeed, Charles Penrose, G. D. Rosengarten, W. C. Wetherill; (to serve two years), Malcolm Lloyd.

The Chairman of the meeting then declared the candidates named to have been elected to their several offices.

The statement was made by the Secretary that the Tellers had devoted four hours to the reception and tabulation of the ballots and requested that a vote be passed, thanking the Tellers for their intelligent and helpful efforts. Such a motion was presented and was unanimously adopted.

There being no other business, the Acting President introduced as the speaker of the evening Professor Charles P. Olivier, Director of the Flower Astronomical Observatory of the University of Pennsylvania, who spoke convincingly and delightfully on "The Influences of Meteoric Astronomy on Evolution." His paper was followed by discussion.

The meeting was adjourned at nine-thirty-four, with a rising vote of thanks to Professor Olivier for his delightful talk.

HOWARD MCCLENAHAN,
*Secretary.*

## COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of Stated Meeting held Wednesday, January 2, 1929.)*

HALL OF THE COMMITTEE,
PHILADELPHIA, January 2, 1929.

DOCTOR GEORGE S. CRAMPTON *in the Chair.*

The following reports were presented for first reading:

No. 2840: Klydonograph.
No. 2885: Work of Sir James C. Irvine.
No. 2903 and No. 2904: Franklin Medal.

GEO. A. HOADLEY,
*Secretary to Committee.*

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## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

*(Stated Meeting, Board of Managers, January 9, 1929.)*

RESIDENT.

DR. STUART MUDD, Medical Investigation, Henry Phipps Institute, Philadelphia, Pa. For mailing: Villa Nova, Pa.

NON-RESIDENT.

MR. GEORGE A. HENDRICKSON, Engineer, 2000 Second Avenue, Detroit, Michigan.

DR. ELMER O. KRAEMER, Research Chemist, Director-Research in Colloids, E. I. duPont de Nemours Experimental Station, Wilmington, Delaware. For mailing: 2322 West Fourteenth Street, Wilmington, Delaware.

STUDENT.

MR. CHARLES A. COHEN, Student, College of Pharmacy and Science, Philadelphia Pa. For mailing: 516 Greenwich Street, Philadelphia, Pa.

### CHANGES OF ADDRESS.

JOHN J. CATON, Esq., 16140 Fairfield Avenue, Detroit, Michigan.

DR. E. A. ECKHARDT, Gulf Oil Corporation, Research Department, 903 Law and Finance Building, Pittsburgh, Pa.

MR. H. LINWOOD GODFREY, Fidelity-Philadelphia Trust Building, 123 South Broad Street, Twenty-third Floor, Philadelphia, Pa.

MR. E. S. HIGGINS, Motor Mileage Corporation, 1113 Packard Building, Philadelphia, Pa.

CHARLES HENRY HOWSON, Esq., Fidelity-Philadelphia Trust Building, 123 South Broad Street, Twenty-third Floor, Philadelphia, Pa.

HENRY HOWSON, Esq., Fidelity-Philadelphia Trust Building, 123 South Broad Street, Twenty-third Floor, Philadelphia, Pa.

RICHARD HOWSON, Esq., Fidelity-Philadelphia Trust Building, 123 South Broad Street, Twenty-third Floor, Philadelphia, Pa.
MR. J. C. JOHNSON, 332 North Lansdowne Avenue, Lansdowne, Pa.
DR. JOHN JOHNSTON, Research Laboratory, United States Steel Corporation, Kearny, N. J.
MR. F. B. LYSLE, 4921 Pulaski Avenue, Germantown, Phila., Pa.
DR. J. C. MCLENNAN, 88 Prince Arthur Avenue, Toronto, Canada.
MR. L. W. MACLEAN, Atlantic City Railroad, Camden, N. J.
MR. H. H. PLATT, Villa Bachlyk, Cap d'Ail, A. M., France.
MR. DEXTER N. SHAW, Fidelity-Philadelphia Trust Building, 123 South Broad Street, Twenty-third Floor, Philadelphia, Pa.
MR. GEORGE H. TABOR, 4114 Bigelow Boulevard, Pittsburgh, 13, Pa.

## NECROLOGY.

**Dr. William J. Williams,** Philadelphia.

## LIBRARY NOTES.

### RECENT ADDITIONS

ALEXANDER, JEROME, editor. Colloid Chemistry: Theoretical and Applied. By selected international contributors. Volume 2: Biology and Medicine. 1928.
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## BOOK REVIEWS.

COLLOID CHEMISTRY, THEORETICAL AND APPLIED. By selected international contributors, collected and edited by Jerome Alexander. Volume II, Biology and Medicine. 1029 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1928. Price $15.50.

Notice of the general nature of this work was given in the review of the first volume. The present volume is devoted largely to the biological relations of colloids, a field which is of great extent and necessarily capable of treatment only by an array of specialists. These have been selected from many nations and thus

has been obtained not only an immense amount of detailed information but a multiplicity of view-points. The nearly three score essays have been subjected to the editorial scrutiny of Mr. Alexander, so well-known in this department of physical chemistry.

The text proper is introduced by a preface which takes a more literary tone than usual in the prefaces of scientific works, about a score of lines being quoted from the conversation between Mephistopheles and Wagner, rather unwisely given in the original. Goethe's German is not the simplest and there are excellent standard translations of the drama, which would be very welcome to most of the users of the book. After all perhaps the tempter's insinuations have no more force than the brief sentence of Hobbes that "Words are wise men's counters, they do but reckon by them, but they are the money of fools."

In discussing the bearing of facts upon inference, the editor remarks that "ordinary observation proves that the earth is flat." A strict critic would be inclined to say that ordinary observation *suggests* that the earth is flat, for even comparatively slight careful observation indicates the contrary. Pliny, the Elder, in his essay "That there are or may be Antipodes" instances the curved surface of the sea as an evidence of the spherical form of the earth.

It is impossible to enumerate the many essays in the volume, but one especially attracts attention, because it is contributed by a whilom Philadelphian, in his student days a pupil of the reviewer, who noted and stated at that time, that the boy was destined to occupy a prominent place in the American science. This is Dr. Edgar T. Wherry, who contributes a brief but very important essay on the advantage of stating at times reactions in terms of concentration instead of pH. Dr. Wherry has given much attention to this subject and has pointed out a number of instances in which trained workers have applied the Sörenson method wrongly, from failure to appreciate the fact that the data are reciprocal logarithms and not simple arithmetic relations. Dr. Wherry suggests a system, largely his own, by which relative hydrion-concentrations may be expressed in a simpler way than by the generally used pH method. In connection with Dr. Wherry's paper the editor adds a somewhat extended note, which explains in detail points about the Sörenson method. In this note the expression "pH value" is used, but it seems that "pH number" would be preferable.

A paper of somewhat unusual type is that of Bredig on "Inorganic Ferments." It is interesting to note that one of the earliest instances of catalytic action was reported in 1832 by Döbereiner, namely, the property of manganese dioxide to promote the decomposition of potassium chlorate. It was not until 1836 that Berzelius coined the word "catalysis" to designate such phenomena, now familiar in many phases both in pure and applied chemistry and employed in many industrial procedures.

The now only too familiar lack of contributors from Philadelphia in compendiums of research-work is exhibited in this book. Dr. Wherry is indeed originally from that city but he has for many years been an emigré. One is reminded of the satirical remark (probably of some New Yorker) that the three greatest Pennsylvanians of Colonial times were Robert Morris of England, James Wilson of Scotland, and Benjamin Franklin of Massachusetts.

A work of most extensive and comprehensive type upon a subject of the greatest importance in both theoretical and practical physical chemistry.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 294. The Measurement of Maximum Cylinder Pressures, by Chester W. Hicks. 11 pages, illustrations, quarto. Washington, Government Printing Office, 1928.

The work presented in this report was undertaken to determine a suitable method for measuring the maximum pressures occurring in aircraft engine cylinders. The study and development of instruments for the measurement of maximum cylinder pressures has been conducted in connection with carburetor and oil engine investigations on a single cylinder aircraft-type engine. Five maximum cylinder-pressure devices have been designed, constructed, and tested, in addition to the testing of three commercial indicators.

Values of maximum cylinder pressures are given as obtained with various indicators for the same pressures and for various kinds and values of maximum cylinder pressures, produced chiefly by variation of the injection advance angle in a high-speed oil engine. It is the high pressure of short duration that is most difficult to measure, because the time of its duration is so short that little work can be done to operate an indicator.

The investigations conducted thus far indicate that the greatest accuracy in determining maximum cylinder pressures can be obtained with an electric, balanced-pressure, diaphragm or disk-type indicator so constructed as to have a diaphragm or disk of relatively large area and minimum seat width and mass.

Report No. 300. The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics, by Fred E. Weick and Donald H. Wood. 16 pages, illustrations, quarto. Washington, Government Printing Office, 1928, price ten cents.

This report describes in detail the new propeller research tunnel of the Committee at Langley Field, Va. This tunnel has an open jet air stream twenty feet in diameter in which velocities up to 110 M.P.H. are obtained. Although the tunnel was built primarily to make possible accurate full-scale tests on aircraft propellers, it may also be used for making aerodynamic tests on full-size fuselages, landing gears, tail surfaces, and other aircraft parts, and on model wings of large size.

DIE TECHNIK ELEKTRISCHER MESSGERÄTE. Von Dr. Ing. Georg Keinath. Dritte, vollständig umgearbeitete Auflage. Erster Band: Messgeräte und Zubehör. Zweiter Band: Messverfahren. 2 volumes, illustrations, 8vo. München & Berlin, R. Oldenbourg, 1928, price in cloth, 59.50 marks, paper 55.50 marks.

The present third edition of this work has been thoroughly revised from the text of the former editions. The general request made in former reviews for the more extended treatment of the subjects has been carried out by the author as far as possible. By reason of this enlargement it has been necessary to publish the work in two parts, the texts of which have been made to include in one volume the measuring apparatus and accessories, and in the other, procedures. A special addition to the first volume is a section on the materials for the construction of electrical measuring apparatus, comprising many of the special forms. Though

the author has gone rather fully into the construction of the apparatus it is not his intention to present a manual in that field, but only to acquaint the reader with the details of the various forms that he may be more familiar with their nature and use thus giving more information than in most of the works at hand. This perhaps involves some critical examination of the apparatus and procedures, the inclusion of which adapts the book to use in high schools and professional institutions.

In the second volume the procedures of measurement are described fully. In addition to the usual procedures for the measurement of electrical units there is included information concerning non-electrical data such as velocity, acceleration, pressure and magnetic measurement. In both volumes the general conditions for accurate determinations are carefully set forth and the source of error and uncertainty are pointed out so that the highest degree of accuracy may be secured.

In this as in former editions the author has endeavored to present a work suitable to the practicing engineer without many complicated formulas or unrelated matters such as are often found in works of this type. The book, therefore, is suited to those who wish to carry out their own measurement and have not been able to follow closely the technical literature of the subject. The work is excellently printed and liberally illustrated. It is gratifying to note the extensive quotation of British and American literature.

HENRY LEFFMANN.

INDUSTRIAL CARBON. By C. L. Mantell, Ph.D., Pratt Institute, Brooklyn, Member, American Institute of Mining and Metallurgical Engineers, American Institute of Chemical Engineers. 410 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928. Price, $4.50.

This book is loaded with interesting and valuable information. It covers only forms of elemental carbon, or substances in which elemental carbon is the active constituent. The immense field of the carbon compounds is, therefore, untouched. Its field of application is extensive and is increasing at a rapid rate. The use of asphyxiating gases in the late war gave a great impetus to the study of the adsorptive powers of the known forms of char and the information thus gained has found valuable application in industrial operations. Carbons of very high adsorptive powers are now on the market and are employed in many ways. The methods of manufacture, properties, uses, and nature of the several forms are set forth in detail. Many illustrations add to the value of the book.

A brief chapter is given on the Diamond with illustrations of scenes at the great mines in South Africa which have so profoundly modified the economic and aesthetic relations of the gem. The curious fact is noted that the more important precious stones are so indifferent to wetting, that a mixture of them with the common crystals such as quartz, zircon, magnetite, can be carried by a current of water over a greasy cloth while the precious stones will be caught in the grease. This property is utilized with much success in separating diamonds from the inferior stones.

Graphite next claims attention, both the natural and artificial forms being described and their properties and uses set forth.

As might be expected the larger portion of the book is devoted to carbon in the amorphous form as obtained from animal and vegetable materials. The methods

of activating these chars and the principles on which this activation is based are given full attention. A brief chapter on charcoal as a fuel is included, but the fuel uses of carbon are wholly outside the scope of the book. The different forms of amorphous carbon have found an astonishing number and variety of uses, such as inks, paints, and in producing a hard exterior on iron. The latter procedure is very old, but has found much employment of late. The most remarkable chapter in the history of carbon black is its extensive use during the last ten years in the rubber trade. After long research, chemists of the rubber companies found that carbon black will make tires tougher and more serviceable. The use began tentatively with some American manufacturers but is now world-wide. Carbon black is also used in many other rubber compositions in which resistance to wear is especially important such as hose, flooring material and surgical rubber articles. Lampblack also receives full attention in the book.

So many and so varied are the uses of elemental carbon as set forth in this work that it reads like one of the familiar popular introductions to science, but it is strictly scientific, though the editor indulges in a little rhetoric in the preface. In some cases careless phraseology has been noted. On p. 138 it is stated that "in the form of wood ashes," carbon has been used as an eliminant, and on p. 192 it is stated that charcoal is obtained by "burning wood in a closed vessel." These slips are of minor moment and do not detract from the high practical value and excellent character of the book.

HENRY LEFFMANN.

THE FUNDAMENTALS OF QUANTITATIVE ANALYSIS. Third edition. By Walter C. Blasdale, Ph.D., Professor of Chemistry in the University of California at Los Angeles. 403 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928. Price, $3.75.

The first and second editions of this work appeared under the title "Principles of Quantitative Analysis." The text has largely been rewritten and this revision is regarded by the author as justifying the change of title. It does not seem that anything of value to the user of the book has been obtained by this change, for the primary object of the present edition is the same as that of the early ones, namely to give in some detail the features of a series of exercises in quantitative analysis, presenting the usual material arranged for the year's course of students who have had at least one year's work in general chemistry. There is a very large number of such books now available in this country. The time seems to be near at hand for the application of the principles of standardization such as are so much in vogue in many of our industries, indeed we might also hope for a development of the "merger spirit" which is affecting many of our financial and public utility corporations.

Chemistry is an exact science and while in analysis there may be several good methods for certain purposes there is generally a best one and would seem that this should be used to the exclusion of the others unless there was some very serious reason to the contrary. In this edition a section of the earlier editions dealing with the use of physio-chemical processes has been eliminated being considered of sufficient importance to be treated in a separate volume, and because the author has found the treatment of them within the year-period not satisfactory. Questions are given in connection with the various topics but it seems to the reviewer

that these might be best left to the suggestion of the teacher. There is a very large amount of valuable information contained in the book.

HENRY LEFFMANN.

HANDBUCH DER EXPERIMENTALPHYSIK. Band 13, 2. Teil. Physik der Glühelektroden, by Prof. Dr. W. Schottky and Dr. Ing. H. Rothe, 55 illustrations; Herstellung der Glühelektroden, by Dr. Rer. Techn. H. Simon, 36 illustrations; Technische Elektronenröhren und ihre Verwendung, by Dr. Ing. H. Rothe, 88 illustrations. 492 pages. Edited by W. Wien and F. Harms with the collaboration of H. Lenz. Leipzig, Akademische Verlagsgesellschaft M. B. H. 1928.

This volume which is one of the series comprising the "Handbuch der Experimentalphysik" (Handbook of Experimental Physics) is typical of the extensive and thorough treatment accorded the subjects of its contemporary volumes. The subject matter has been divided into three parts. Part one, The Physics of Incandescent Electrodes is presented in an able and comprehensive manner by W. Schottky and H. Rothe. The authors have sought to treat the problem of the emission of electrically charged particles from hot bodies in the light of thermodynamical considerations rather than statistical. The term. "$\mu$-thermodynamics" is employed to designate the application of the regular thermodynamic equations to the characteristics of individual electrified particles, Particular attention is paid to the correlation between theoretically calculated values and those obtained experimentally. In this connection the investigation of thermionic emissions by Langmuir and associates received particular attention.

Part two, on the "Preparation of Incandescent Electrodes," written by H. Simon, has a preliminary study upon the characteristic emissions of polished metals, metals coated with other metals possessing a high emissivity and metals having a coating of metallic oxide. Methods for producing a high vacuum, measuring the same, determining temperature and preparing a glowing cathode tube are treated all with considerable detail.

Part three, by H. Rothe, on Technical Electronic Tubes and their Applications, embraces a discussion upon the present day widespread use of vacuum tubes as amplifiers, oscillators and detectors. Characteristic curves and equations are given indicating the performance of various types of tubes and their seemingly infinite variety of hookups.

The book is an excellent treatise and a general work of reference upon the subjects in question and the authors are to be commended for their compilation and critical treatment of the subject matter presented therein.

T. K. CLEVELAND.

VIBRATION PROBLEMS IN ENGINEERING. By S. Timoshenko, Professor of Engineering Mechanics, University of Michigan. vi–351 pages, illustrations, 8vo, cloth. New York, D. Van Nostrand Company, Inc., 1928. Price, $4.50.

Among the numerous specialties of modern engineering practice, the study of the vibration of machines and of structures which carry moving loads, and problems of kindred nature may justly claim to have achieved a position of

recognized importance. In the past, vibrations of machines, and their more or less injurious and sometimes decidedly unpleasant effects upon the immediate surroundings were more often endured than cured. Now, they are more often cured or prevented by the application of century-old principles which have only needed the quickening touch of modern vision. A member of this Institute, Mr. N. W. Akimoff, one of the initiators of the modern practice of vibration engineering, during the trying months of our entry into the Great War, by the application of these principles, it is related, won the distinction of putting into service a much-needed naval vessel which had proved quite useless for its intended purpose on account of destructive vibration at high speeds.

Professor Timoshenko develops fully the theory of vibrations, its formulation and its application to the solution of technical problems. This he illustrates by various examples, in many cases, taken from actual experience with vibration of machines and machines in service. The subject-matter is based upon a series of lectures on vibration which he delivered before the mechanical engineers of the Westinghouse Electric and Manufacturing Company during the year 1925. The treatment is rational and deductive in first dealing with general equation of motion and then passing to specific cases. The list of topics is long and representative, and their treatment thorough and practical.

LUCIEN E. PICOLET.

ENZYME ACTIONS AND PROPERTIES. By Ernst Waldschmidt-Leitz, Institut für Biochemie, Deutsche Technische Hochschule, Prag., formerly at the University of Munich. Translated and extended by Robert P. Walton, Department of Organic Chemistry, Columbia University. 255 pages, illustrations, 8vo. New York, John Wiley & Sons, Inc., 1929. Price, $4.

The nature and mode of action of enzyms are among the most interesting and difficult problems of organic chemistry. The subject is especially associated with bio-chemistry, since a large group of enzyms are produced only in living tissues. The present work is limited to this group, but the enzymist must not overlook the part played by inorganic bodies in actions essentially similar in result to those produced by those of organized origin. Broadly speaking, all substances that affect the speed or products of a reaction without being themselves changed may be classified as catalysts, and there is no necessity for culling out the organic phenomena and designating them by a special name. It is the province of science to connect objects and phenomena that are analogous as well as to distinguish them when the analogy is only apparent.

The present work is a translation from German with considerable additions. The original is not available to the reviewer, and no judgment can be made as to the general accuracy of the translation nor as to the extent of the additions, but as the translator has been closely associated with the author and has had the latter's direct assistance during the preparation of the book, it is evident that the original is correctly represented. In the course of reading, a single inadvertence has been noted, the adjectives "formed" and "unformed" are used to designate the old distinctions between "organized" and "unorganized" ferments, and the former terms are given as the accepted English terms, but they were not so used.

The work covers a wide field within the specific limits assigned to it, that is, the enzyms producing changes in organic substances. Modern research, partly

encouraged by an earnest search for facts and partly by economic impulse has brought to our knowledge a very large number of substances that can be classified as catalysts, a notable portion of which are operative only in the inorganic field. As far as possible the reactions which are brought about by the action of enzyms on organic substances are set forth fully in this book, and the details of molecular changes also when known. It does not appear clear to the reviewer why the reaction of urease on urea should be described as resulting in tetrahydroxymethane and ammonia, when the reaction can be more simply and satisfactorily expressed as a conversion of the urea into ammonium carbonate which then ionizes under standard conditions.

Some interesting and important information is given concerning Pasteur's work in contrast to that of Buchner. There has been some sharp discussion lately on this subject, it being claimed that Buchner has been badly treated by those who are presenting Pasteur's work to the world. It seems established that Buchner first introduced the work "zymase" and gave it the proper signification.

It is an advantage to American chemists to have this book in their own language. The world owes much to Germans, and chemistry is especially under obligations, but while those of us who are familiar with their language, appreciate its merits and enjoy its vast literature, there is no doubt that it is a difficult tongue to all who are not "native and to the manner born."

Science has enjoyed about a decade of peaceful internationalism in which all workers are coöperating for the discovery of truth and its applications to the benefit of mankind, but were Cassandra alive to-day she could say:

"Eine Fackel seh' ich gluehen,
Aber nicht in Hymen's Hand;
Nach dem Wolken seh' ich's ziehen,
Aber nicht wie Opferbrand."

"Coming events cast their shadows before" and the dark shadow of war lies over the laboratories.

HENRY LEFFMANN.

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## PUBLICATIONS RECEIVED.

*Colloid Chemistry Theoretical and Applied*, by selected International Contributors. Collected and edited by Jerome Alexander. Vol. II Biology and medicine. 1029 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1928, price $15.50.

*Memoirs and Addresses of Two Decades*, by Dr. J. A. L. Waddell, Consulting Engineer. Edited by Frank W. Skinner, Consulting Engineer. First edition. 1174 pages, illustrations, 8vo. Easton, Penna., Mack Printing Company, 1928.

*Die Technik Elektrischer Messgeräte*, von Dr. Ing. Georg Keinath. Erster band, Messgeräte und Zubehör; zweiter band, Messverfahren. 2 vols, illustrations, 8vo. München, R. Oldenbourg 1928, price, bound, 59.50 marks.

*Le Temps Absolu et l'Espace a Quatre Dimensions* (*La gravitation—La masse—La lumière*), par Emile Sevin. 127 pages, illustrations, 8vo. Paris, Albert Blanchard, 1928, price 22 marks.

*National Advisory Committee for Aeronautics.* Fourteenth annual report, 1928. Administrative report without technical reports. 80 pages, quarto. Washington, Government Printing Office, 1928, price twenty cents.

*Deforested America.* Major George P. Ahern. Foreword by Gifford Pinchot. 79 pages, 12mo. Washington, D. C., 1928, price twenty cents.

*Introduction a la Physique des Rayons X et Gamma*, par MM. Maurice de Broglie et Louis de Broglie. 201 pages, illustrations, 8vo. Paris, Gauthier—Villars et Cie, 1928, price 50 francs.

*The Spectroscopy of the Extreme Ultra-Violet*, by Theodore Lyman, Ph.D. Second edition. 160 pages, illustrations, 8vo. London and New York, Longmans, Green & Company, 1928, price $3.75.

## CURRENT TOPICS.

**The Green Flash at Sunset.** S. J. BARNETT. (*Nature*, August 4, 1928). For decades observers have published in *Nature* their descriptions of this supposedly rare sky phenomenon. Now Professor Barnett dispels the illusion of its rarity, at least in California, saying: "Here in Southern California in the last two years I have seen the flash many times as the sun has set over the Pacific Ocean, or over the Santa Monica Mountains a few miles west of our residence. At least once I have seen the color of the flash change distinctly from green to blue or blue-green before disappearance."

G. F. S.

**The Critical Point of Monel Metal.** L. F. BATES and R. C. BROWN. (*Nature*, Aug. 18, 1928.) Monel, metal made from a natural ore found in Ontario, is an alloy of 67 per cent. nickel, 28 per cent. copper and 5 per cent. of other metals. It shows great resistance to corrosion. While it is ferromagnetic its critical point is unusually low. "It may conveniently be used for a laboratory experiment to illustrate the loss of ferromagnetism with rise of temperature. The magnetic critical temperature varies from specimen to specimen, and is stated to lie between 100° and 150°. This appears to apply to specimens in the form of the stout bars supplied commercially, but specimens in the form of anchor rings of diameter 10 cm. and 1 cm. thickness supplied to us possess critical temperatures of 70° C."

G. F. S.

**The Stark Effect at Very High Field.** YOSHIO ISHIDA. (*Nature*, Aug. 25, 1928.) Ishida has attained an electrical field of 650,000 volts per cm. and believes that the limit has not yet been reached. A quartz tube of the Lo Surdo type was used. The excitation was furnished by a transformer with a synchronous motor rectifier having its vanes set for the most favorable phase.

With this apparatus certain lines of the helium and lithium spectra were affected that have been hitherto obdurate to the electrical field.

G. F. S.

**The Waves of an Electron.** GEORGE P. THOMSON. (*Nature*, Aug. 25, 1928.) In the science of physics it is not common for

both a father and a son to be investigators. In the United States we have Henry Crew and his son while in Great Britain the two Rayleighs come to mind. At the present time there are also Sir J. J. Thomson and his son G. P. Thomson, of the University of Aberdeen, who delivered at the Royal Institution, June 8, 1928, the lecture of which this article is a report. Some account of the same matter was published in the JOURNAL OF THE FRANKLIN INSTITUTE, Sept., 1928, page 417.

At the beginning of the present century the wave theory of light was regarded as impregnably established. It had driven the corpuscular theory not only from the field but even into contempt. All the evidence of interference and diffraction was in favor of the wave theory. Then new phenomena clamored for recognition. In the field of photoelectricity it was found "that light could communicate an amount of energy to an electron which only depended on the kind of light and not at all on the intensity. If light consists of continuous waves this seems almost impossible; but it is just what we should expect if, as Newton firmly held, light is due to a stream of corpuscles. In such a case, if one of these hit an electron, it would give to it an energy which would be quite independent of the number of other corpuscles present in the stream, that is, of the intensity of the light. Louis de Broglie has hit on a brilliant synthesis of the two views. Put briefly, it comes to saying that light is indeed corpuscular, but that the corpuscles are accompanied and guided by waves." One of de Broglie's results is that the wave-length of the waves escorting any particle equals Planck's constant $h(6.57 \times 10^{-27})$ divided by the momentum of the particle. By this relation the wave-length of an electron with the energy of 150 volts is $10^{-8}$ cm., about that of a soft X-ray. Another deduction from de Broglie's theory is that the square of the velocity of the waves equals the square of the velocity of light increased by a quantity proportional to the square of the lengths of the accompanying waves. Thus the velocity of the waves varies with their length, i.e., there is dispersion even in a vacuum.

The predictions of de Broglie's theory were confirmed by the experimental results of Davisson and Germer in the United States ("Are Electrons Waves?" this JOURNAL, May, '28). They projected a stream of electrons upon the face of a nickel crystal and observed that they are reflected much as a beam of light is reflected. Thompson, in turn, undertook the study of the possible diffraction of cathode rays. "De Broglie's theory is quite a general one, and should apply to any sort of corpuscular motion." He, working with Reid, let cathode rays impinge on very thin films of metals and celluloid. The rays were received on a photographic p ate after

they had been diffracted. The measurement of the images there formed made possible a comparison of theory and result. From the size of the rings on the plate it was calculated that the wave-length was really inversely proportional to the momentum, as by theory it should be. Diffraction of cathode rays by mica also is reported by Nishikawa and Kikuchi, Tokyo, in *Nature*, June 30, '28. They obtained a pattern consisting of "three sets of parallel bands intersecting each other at an angle of 60°, forming a net of triangular mesh, of which the net points are arranged into an array of spots." A change in the applied voltage caused a change in the distribution of the spots. Since cathode rays are deflected by a magnetic field, the application of such a field to the path of the rays shifts the photographic impression.

"What are these waves? Are they another name for the electron itself? How many waves in series does an electron have? Here we have a little direct evidence. The sharpness of the rings depends, among other things, on this length. A short train of waves results in blurred rings. I calculate that there must be at least 48 ordered waves in the series."

"As regards the relation between electron waves and light waves: they are certainly not the same, even when their wave-lengths are equal. They go at different speeds: one is refracted by electric and magnetic fields, while the other is not; their penetrating powers in ordinary matter are widely different. If they are the actual motion of an ether, it must differ in some way in the two cases.

"The easiest way of looking at the whole thing seems to be to regard the waves as an expression of the laws of motion. The uniform motion of Newton's first law is replaced by a simple plane wave, and so on. On this view, the electron remains the reality, and this seems right, for after all it is the electron as a particle which is actually detected in any practicable experiment, and the waves come to bear the same sort of relation to it that Newton's or Einstein's law of gravitation bears to the planets which obey it."

G. F. S.

**The Constitution of Zinc.** F. W. ASTON. (*Nature*, Sept. 8, 1928.) Dempster concluded that zinc is a complex element having three strong isotopes 64, 66 and 68 and one weak one, 70. There was also a suggestion of 67. Aston now gets results by using zinc methyl agreeing in general with Dempster's conclusions. "The mass-spectra indicate that zinc consists of seven isotopes 64(*a*), 65(*e*), 66(*b*), 67(*d*), 68(*c*), 69(*g*), 70(*f*). The letters in brackets indicate the order of intensity. Three of these mass-numbers, 65, 69, 70, are isobaric with those of copper, gallium, and germanium respectively."

G. F. S.

**Some Recent Work on the Light of the Night Sky.** LORD RAYLEIGH. (*Nature*, Sept. 1 and 8, '28.) The light of the night sky with the sun 18° below the horizon and the moon not yet up has little resemblance to the light of the sky by day. Light from the night sky shows very little polarization and is so faint as to be below the threshold of color vision so that ascriptions of color are illusory. By the use of colored glasses it has been found that the day sky is much richer in blue than the night sky.

When a spectroscope resolves the light of the night sky the eye sees the green auroral line of wave-length 5577 Å. against a background of a seemingly continuous spectrum. Some observers can always see this line but Lord Rayleigh can see it only sometimes while others never are able to perceive it. Photographic examination of the light is reduced in value by the very long exposures requisite with such faint illumination. The green line can be photographed by an exposure of one night but several nights are needed to get records of certain emission and absorption lines. "An exposure of many nights on an Ilford panchromatic plate failed to show anything in the red region of the spectrum. It is noteworthy that the negative bands of nitrogen, which are the most important features in the photographs of the auroral spectrum, are not present in the night sky."

The difficulties presented by the application of spectroscopy and photography to the problem of observation have caused Lord Rayleigh to turn to photometry. To analyze the light of the night sky three color filters were used. One transmitted almost no light but that of the green line, a second transmitted the light falling in the spectrum between this line and the red limit while the third let the light pass that lies to the short wave-length side of the same line. Self luminous crystals of potassium-uranyl sulphate furnished the standard light for comparison. The radioactivity of the uranium is the cause of the fluorescence of the salt which in a sealed vessel is constant for years.

With a Lummer cube the light of the night sky was matched with the standard, neutral glasses being used to reduce the intensity of either component light until a match was obtained. An unfortunate typographical error confuses the understanding of the tabulated results of observations. Observations were made at about fifteen stations in Europe, North and South America, Asia, Africa and Australia as well as on two voyages. "Fairly normal values can be stated for the intensity of each component at any part of the world." The normal value for the auroral light lies in intensity between those for blue and red but much nearer to that of the red. "There is a strong correlation between the red and

the auroral intensities on any given occasions, and a rather less strong but still marked correlation between these and the blue. It is, however, definitely established that this correlation is not complete."

When the intensity of the auroral light is studied from month to month it is seen that in general a marked fall occurs from October to December. There is partial recovery with a secondary maximum in March. The main annual maximum probably would be found not far from July but residual daylight interferes with observations at that time of year. The intensity in August is about 1.6 that in April. 1923 was a year of sunspot minimum while 1928 should have a maximum. During this five year interval there has been a general increase in the brightness of the night sky.

The author compares the polar aurora limited to zones with the non-polar aurora observable all over the earth. Both have the green line 5577 Å. due to oxygen. The polar aurora alone shows the negative nitrogen bands, the forms of arcs and draperies and rapid changes of intensity.

A better way of studying night light with a photoelectric cell is under development. With it some hints of diurnal periodicity in the intensity have appeared. G. F. S.

**The Newly Announced Raman Effect.** (See this JOURNAL for August, 1928, page 276.) *Nature*, Sept. 8, '28, contains the following comment by R. W. Wood: "Professor Raman's brilliant and surprising discovery that transparent substances illuminated by very intense monochromatic light scatter radiations of modified wave-length, and that frequency difference between emitted radiation and one exciting medium is identical with frequency of infra-red absorption bands, opens up wholly new field in study of molecular structure. I have verified his discovery in every particular, using improved apparatus which makes it possible to photograph strongest lines in few minutes." The conciseness of expression is due to transmission by cable. Like Raman Professor Wood found in the scattered radiation not only wave-lengths longer than those of the exciting radiation but also shorter wave-lengths, "anti-Stokes' terms" he calls them. In the photograph of the spectrum of the light scattered by benzene illuminated by the 4358 Å. group of lines of the mercury arc, published by Raman and Krishnan, *Nature*, July 7, '28, two such modified lines of shorter wave-length are seen. "Measurements show that their frequencies exceed that of the latter (the exciting 4358 line) by the infra-red frequencies of the molecule." They interpret the occurrence of these lines of shorter wave-length as furnishing experi-

mental confirmation of the process of the negative absorption of energy predicated by Einstein in his derivation of Planck's radiation formula and also employed in the Kramers-Heisenberg theory of dispersion. "The presence of these lines proves simultaneously the existence in the liquid of molecules at levels of energy correspondingly higher than the normal, and the fact that the incident radiation induces a return to a lower state of energy; in other words that there is a negative absorption of the radiation." This interpretation is sustained by Ruark, *Nature*, Sept. 1, '28, but disagreement is expressed by Saha, Kothari and Toshniwal, *Nature*, Sept. 15, '28, who say: "We wish to point out that Raman and Krishnan's experiment is not, strictly speaking, a confirmation of Einstein's negative or stimulated emission, as mentioned by these authors, but of the analogous case of negatively modified scattering discussed by Smekal." In 1923 Smekal, basing his conclusion on the considerations advanced by Einstein and Ehrerfest, pointed out that three different wave-lengths of light should be scattered from an assembly of particles on which falls radiation of a single wavelength. These three kinds are (*a*) light of the same frequency as the incident light, (*b*) light whose frequency equals the incident frequency increased by a certain frequency, and (*c*) light whose frequency equals the incident frequency diminished by the same frequency as is added in (*b*). This added or subtracted frequency is calculated by dividing $h$, Planck's constant, into the difference between the energies of the scattering particles in the excited and the normal states.

Raman and Krishnan (*Nature*, Aug. 25, 1928) state: "The appearance in the spectrum of monochromatic light diffused by fluids, of new lines of modified frequency, gives us a powerful, accurate and convenient method of exploring molecular spectra, especially in the near and extreme infra-red regions. We have only to photograph the spectrum of the scattered light, and the frequency-differences between the incident light and the new radiations excited by it give us the molecular frequencies." Wood in the article quoted above adds "Raman's discovery thus makes possible investigations in remote infra-red regions hitherto little explored owing to experimental difficulties. It appears to me that this very beautiful discovery, which resulted from Raman's long and patient study of phenomena of light scattering, is one of the most convincing proofs of the quantum theory of light which we have at the present time."

Ruark (loc. cit.) calls for a quantitative proof that the Raman effect is not merely fluorescence. This question could be settled by finding whether any interval of time elapses between the recep-

tion of the incident light and the emission of the scattered radiation. The interval in the case of rhodamine is $2 \times 10^{-8}$ secs.

Ramdas (*Nature*, July 14, '28) reports that he has obtained the Raman effect in the vapor of ether. With the plates and apparatus used in getting this result he photographed the spectrum of the zodiacal light with an exposure of less than an hour. Saha, Kothari and Toshniwal (loc. cit.) in considering the emission in the scattered light of wave-lengths shorter than that of the incident light raise the question of the proper application of the word 'scattering' to the phenomenon. In scattering by fog particles the process causes no change in the particles. In absorption of radiation the energy absorbed produces a change in the configuration of the atom by separating an electron from the nucleus. "This phenomenon (the emission of waves of higher frequencies) is just intermediate between the two, as the incident light reacts on the particle, and robs it of its internal energy and is re-emitted as a new radiation of increased frequency."

**International Conference on Bituminous Coal, 1928.**—Twelve major topics for discussion at the Second International Conference on Bituminous Coal to be held under the auspices of the Carnegie Institute of Technology, Pittsburgh, Pa., November 19–24, 1928, are tentatively announced.

Although the Second International Conference will be similar in purpose to the first Congress held in 1926, preliminary plans for this year's meeting show that its scope will be considerably enlarged and the program will be more important and more international in character. The discussion of Fixed Nitrogen is one of the topics which will receive close attention. The liquefaction of coal, which was one of the principal subjects of discussion at the first meeting, will again occupy a prominent place in the deliberations. Low temperature distillation will be treated by representatives of at least a half dozen countries. High temperature distillation, power from coal, coal tars and oils, complete gasification of coal, origin of coal, coal washing, pulverized coal, catalysts, and the general aspects of the bituminous coal industry are other topics that will be considered.

The Economics of the Coal Industry will be discussed by Lord Melchett. Dr. Friedrich Bergius, Professor Dr. Franz Fischer, Germany; Andre Kling, and E. Audibert, France; Engineer Guardabassi, Italy; will deal with the subject of the liquefaction of coal.

Low Temperature Distillation will be treated by George E. K. Blythe, Dr. C. H. Lander, Harald Nielsen, Dr. E. W. Smith, England; Dr. A. Herz, Joseph Plassmann, Professor F. P. Kersch-

baum, Germany; Henri Lafond, Professor Paul Lebeau, Antonie Vonk, A. Leaute, France; Professor Dr. Granigg, Austria; Professor Yoskikiyo Oshima, Japan; Professor Samuel W. Parr, Professor Alfred H. White, and F. C. Greene, United States.

High Temperature Distillation: Jean Bing, France; Professor Ernest Terres, Germany; Edgar C. Evans, England.

Power from Coal: Dr. J. E. Noeggerath, Germany; C. Simon, France; A. T. Stuart, Canada; W. B. Chapman and Professor A. G. Christie, United States.

Coal Tars and Oils: Henri Winckler, France; Dr. L. Edeleanu and Professor Dr. Fritz Frank, Germany; and Gustaf Egloff, United States.

Gasification of Coal: Dr. Karl Bunte and Dr. Alfred Pott, Germany; Paul Weiss, France.

Origin of Coal: Professor George L. Stadnikoff, Russia; Dr. Chozo Iwasaki, Japan; Dr. Reinhardt Thiessen and Professor E. C. Jeffrey, United States.

Fixed Nitrogen: A representative of L'Air Liquide Societe, France; Rudolf Battig, Germany; Professor Harry A. Curtis, Louis C. Jones, and Charles J. Brand, United States.

Coal Washing: A. France, Belgium; Professor Dr. Glinz, Germany; Dr. R. Lessing, England; F. R. Wadleigh, Dr. F. W. Sperr, James B. Morrow, and Byron Bird, United States.

Pulverized Coal: Dr. I. P. Goosens, Rudolph Pawlikowski, and Dr. P. Rosin, Germany; C. J. Jefferson, United States.

Catalysts: Professor A. Mailhe, France; Professor Hugh S. Taylor, United States.

Rubber from Coal: Professor Fritz Hoffmann, Germany.

The list of speakers will be considerably enlarged during the coming months, and the final program details will be announced in October.

There were nearly 1,800 delegates at the Conference in 1926 and it is expected that the meeting of 1928 will be more largely attended.

**Moisture Content of Oleomargarine.** ROBERT H. KERR of the Bureau of Animal Industry, U. S. Department of Agriculture (*Jour. Asso. Official Agric. Chemists*, 1928, *11*, 382–386) reports the results of the analysis of 159 samples of oleomargarine, representing 100 different brands, produced by 37 establishments located in 18 cities of the United States. In most of the samples, the moisture content was above 8 per cent. and below 14 per cent. Three types of oleomargarine were examined. The first type included 98 samples and represented 46 brands manufactured in part from the body fats of meat animals, and intended for general use as

butter substitutes. The second type included 45 samples and represented 39 brands manufactured from the same raw materials as those in the preceding class, but intended for use in cooking and baking. The third type included 16 samples and represented 15 brands of so-called vegetable oleomargarine or nut oleomargarine which is made by churning vegetable fats with skimmed milk and contains no fat derived from the carcasses of meat animals. The oleomargarines of the second type usually contained less moisture than those of the other types.

J. S. H.

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